Communication Networks (0368-3030) / Fall 2013

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Network Layer – Forwarding

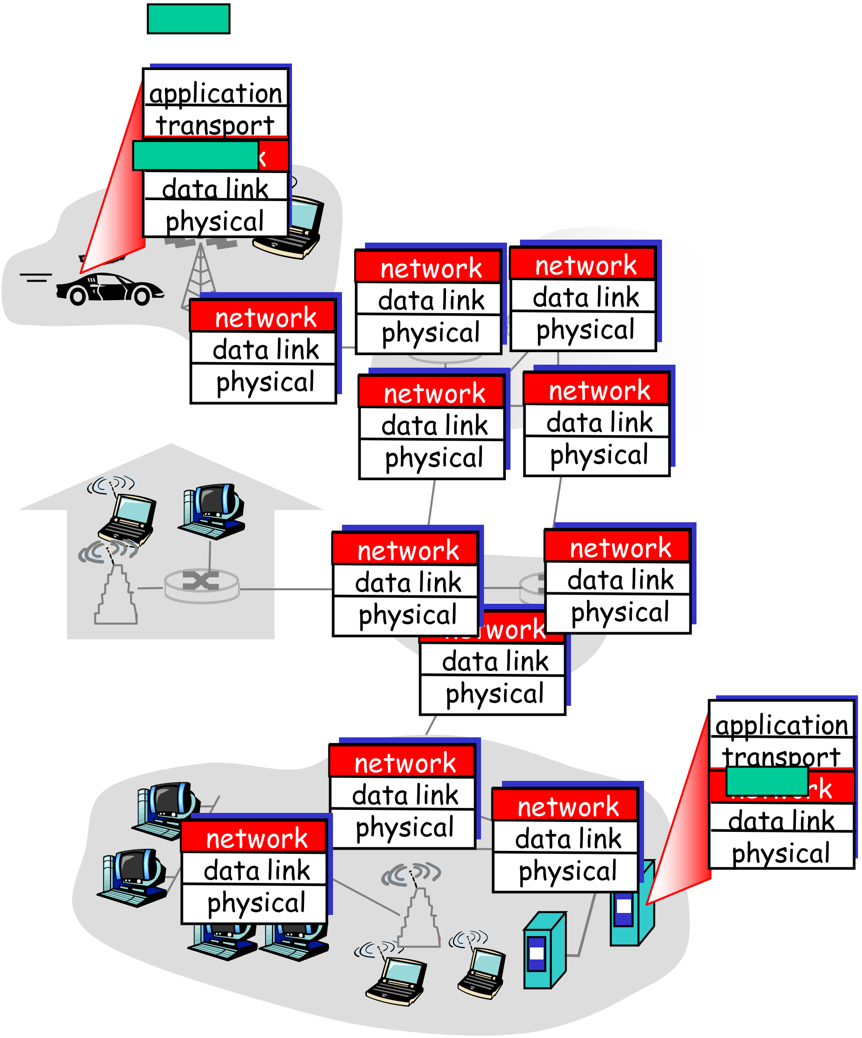
Kurose & Ross, Chapter 4 (5th ed.)

Many slides adapted from:

J. Kurose & K. Ross \
Computer Networking: A Top Down Approach (5th ed.)
Addison-Wesley, April 2009.

Network layer

- transport segment from sending to receiving host
- on sending side encapsulates segments into datagrams
- on rcving 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 Network-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

Network service model

Q: What *service model* for "channel" transporting datagrams from sender to receiver?

example services for individual datagrams:

- guaranteed delivery
- guaranteed delivery with less than 40 msec delay

example services for a flow of datagrams:

- in-order datagram delivery
- guaranteed minimum bandwidth to flow
- restrictions on changes in inter-packet spacing

Network layer service models:

Network Architecture	Service Model	Guarantees ?				Congestion feedback
		Bandwidth	Loss	Order	Timing	
Internet	best effort	none	no	no	no	no (inferred via loss)
ATM	CBR	constant rate	yes	yes	yes	no congestion
ATM	VBR	guaranteed rate	yes	yes	yes	no congestion
ATM	ABR	guaranteed minimum	no	yes	no	yes
ATM	UBR	none	no	yes	no	no

IP provides best-effort service

Virtual circuits

> "source-to-dest path behaves much like telephone circuit"
> - performance-wise
> - network actions along source-to-dest path

- call setup, teardown for each call *before* data can flow
- each packet carries VC identifier (not destination host address)
- *every* router on source-dest path maintains "state" for each passing connection
- link, router resources (bandwidth, buffers) may be *allocated* to VC (dedicated resources = predictable service)

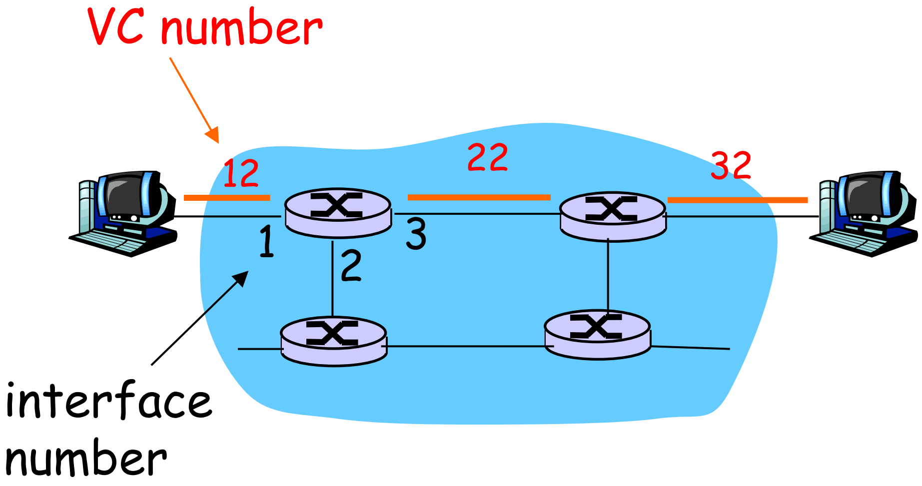
VC implementation

a VC consists of:

1. path from source to destination
2. VC numbers, one number for each link along path
3. entries in forwarding tables in routers along path

- packet belonging to VC carries VC number (rather than dest address)
- VC number can be changed on each link.
  - New VC number comes from forwarding table

VC Forwarding table



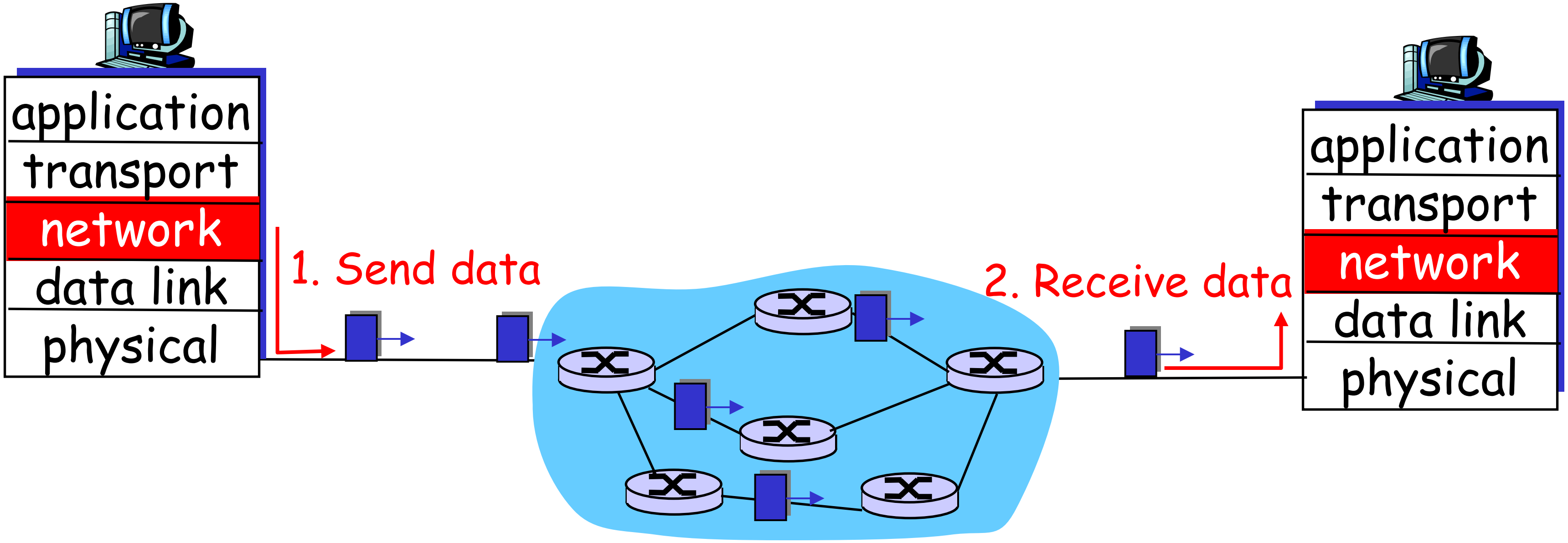
Forwarding table in northwest router:

Incoming interface	Incoming VC #	Outgoing interface	Outgoing VC #
1	12	3	22
2	63	1	18
3	7	2	17
1	97	3	87
…	…	…	…

Routers maintain connection state information!

Datagram networks

- no call setup at network layer
- routers: no state about end-to-end connections
  - no network-level concept of “connection”
- packets forwarded using destination host address
  - packets between same source-dest pair may take different paths



Datagram or VC network: why?

Internet (datagram)

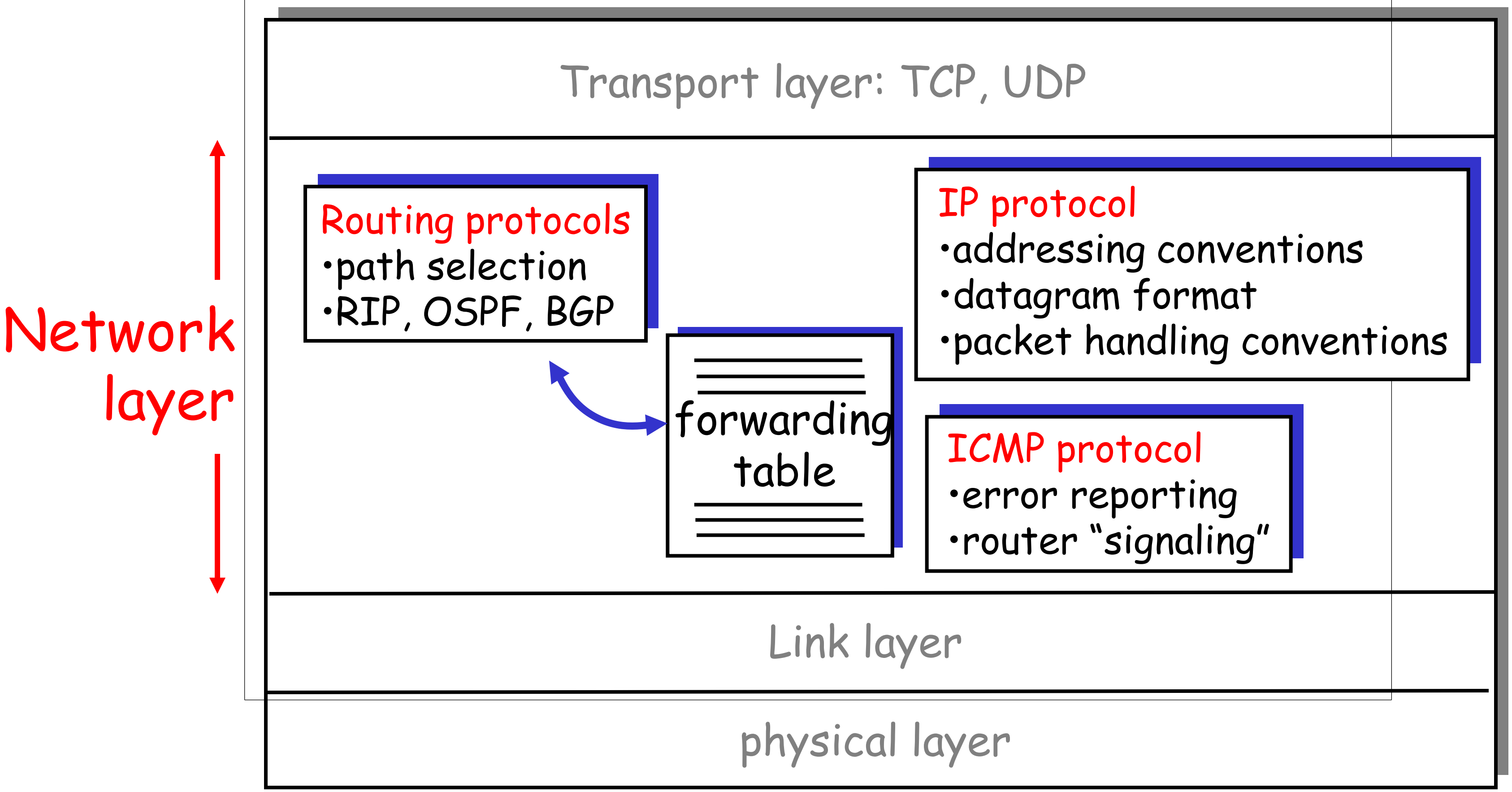
- data exchange among computers
  - "elastic" service, no strict timing req.
- "smart" end systems (computers)
  - can adapt, perform control, error recovery
  - simple inside network, complexity at "edge"
- many link types
  - different characteristics
  - uniform service difficult

ATM (VC)

- evolved from telephony
- human conversation:
  - strict timing, reliability requirements
  - need for guaranteed service
- "dumb" end systems
  - telephones
  - complexity inside network

The Internet Network layer

Host, router network layer functions:



Transport layer: TCP, UDP

Network layer

Routing protocols
- path selection
- RIP, OSPF, BGP

forwarding table

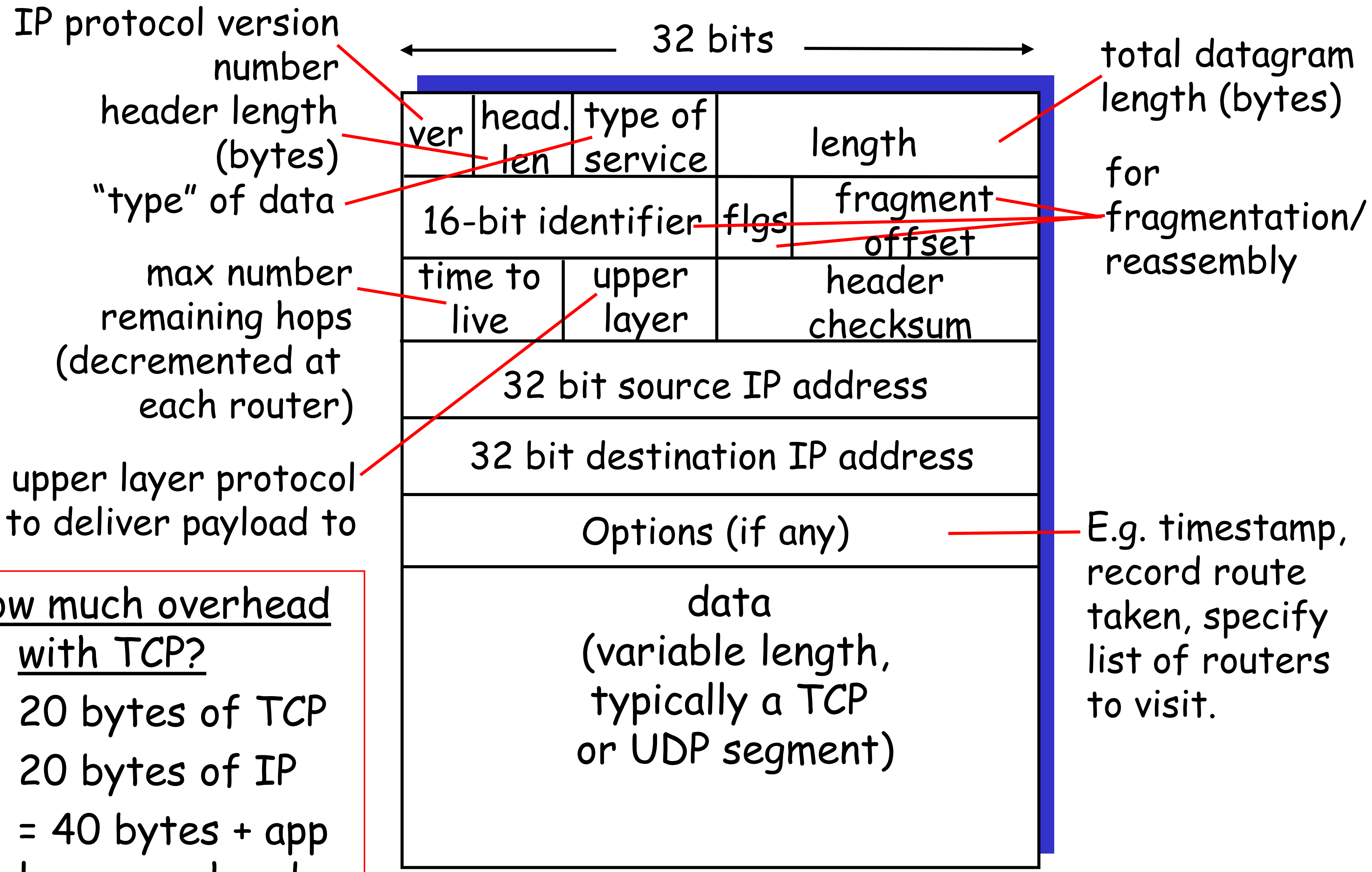
IP protocol
- addressing conventions
- datagram format
- packet handling conventions

ICMP protocol
- error reporting
- router "signaling"

Link layer

physical layer

IP datagram format



IP protocol version number

header length (bytes)

"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.

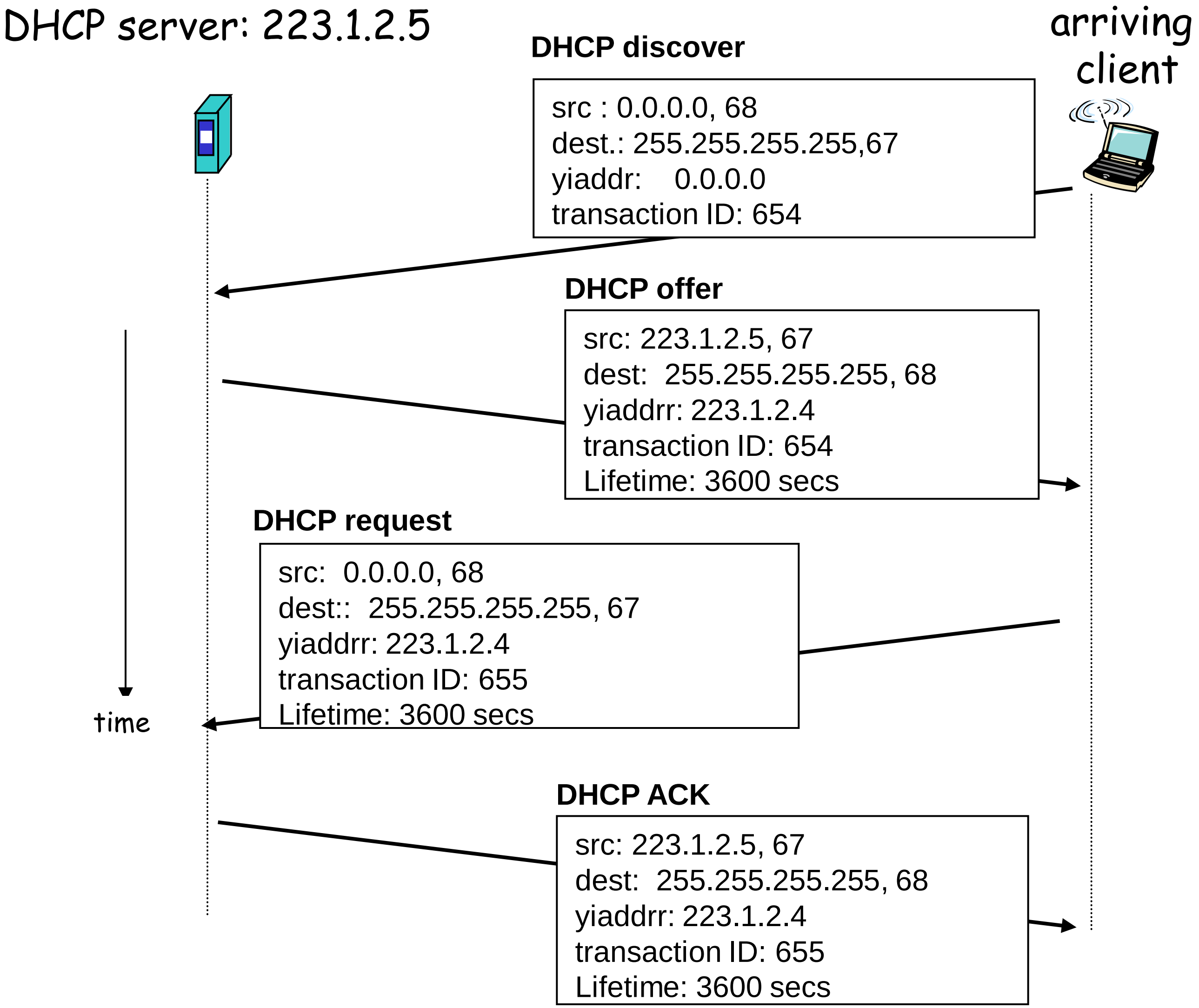
how much overhead with TCP?

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

Dynamic Host Configuration Protocol

- How can a newly connected host get an IP address?
  - (And other useful information: its network mask, an IP address of DNS server etc.)
  - Manual configuration by a system administrator
  - DHCP
    - Plug and play – host obtains this information automatically
    - Defined in RFCs 2131 & 2132.
    - Sent over UDP. Server’s port: 67, client’s port: 68.
    - As usual, we’ll give an overview and not go into all the technical details.

DHCP client-server scenario



DHCP server: 223.1.2.5

arriving client

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

time

DHCP ACK

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

DHCP client-server scenario 1

- Arriving client sends a DHCP discover message
  - Src IP: 0.0.0.0 (“this host”)
  - Dst IP: 255.255.255.255 (“broadcast”)
  - Transaction ID: some number x.
  - Message is broadcast to all nodes on the subnet

DHCP client-server scenario 2

- Server replies with a DHCP offer message
  - Src IP: server’s IP
  - Dst IP: 255.255. 255.255 (“broadcast”)
    - Why? The client still can’t receive direct messages – it has no IP address.
  - Transaction ID: x
  - Message contains the proposed IP address .

DHCP client-server scenario 3

- Why aren’t the previous messages enough?
  - The network might contain more than one DHCP server; a client may receive multiple DHCP offers.
- Client sends a DHCP request message
  - Src IP: 0.0.0.0 (“this host”)
  - Dst IP: 255.255.255.255 (“broadcast”)
    - Why? To allow other servers know their offer was declined
  - DHCP Server ID: the IP of the server whose offer the client wish to accept
  - Transaction ID: some number y

DHCP client-server scenario 4

- Server responds with a DHCP ACK message
  - Src IP: Server’s IP
  - Dst IP: 255.255.255.255 (“broadcast”)
    - The client still doesn’t have an IP address
  - Transaction ID: y

Lease times

- DHCP servers assigns a lease-time for each IP address allocation
    - A client may renew its allocation when it is about to expire
    - A client may relinquish its allocation

Internet Control Message Protocol

- ICMP – defined in RFC 792.
- Carried directly over IP
  - No transport protocol used
- Used by hosts and routers to communicate network layer information – usually report errors.

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

ICMP (cont.)

- For instance: “Destination unreachable”:
  - A router was unable to find a path to host B specified in host A’s request
  - The router sends an ICMP message (type 3) to A to indicate the error
- Another common use: ping
  - Host A sends an ICMP message (type 1) to host B
  - Host B sees this, and replies to A with another type 1 ICMP message.

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)
  - ICMP 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.

Exercise (Peterson & Davie, 5th ed.)

- Suppose A and B have been assigned the same IP address on the same Ethernet, on which ARP is used. B starts up after A.
  - What will happen to A’s existing connections?
  - Every device on the LAN which already has an ARP entry for A, upon receiving a packet from B, will update its ARP table and will now send to B.
  - For instance, if B transmits an ARP query (broadcast!) then all of A’s connections will be cut.

Exercise (Peterson & Davie, 5th ed.)

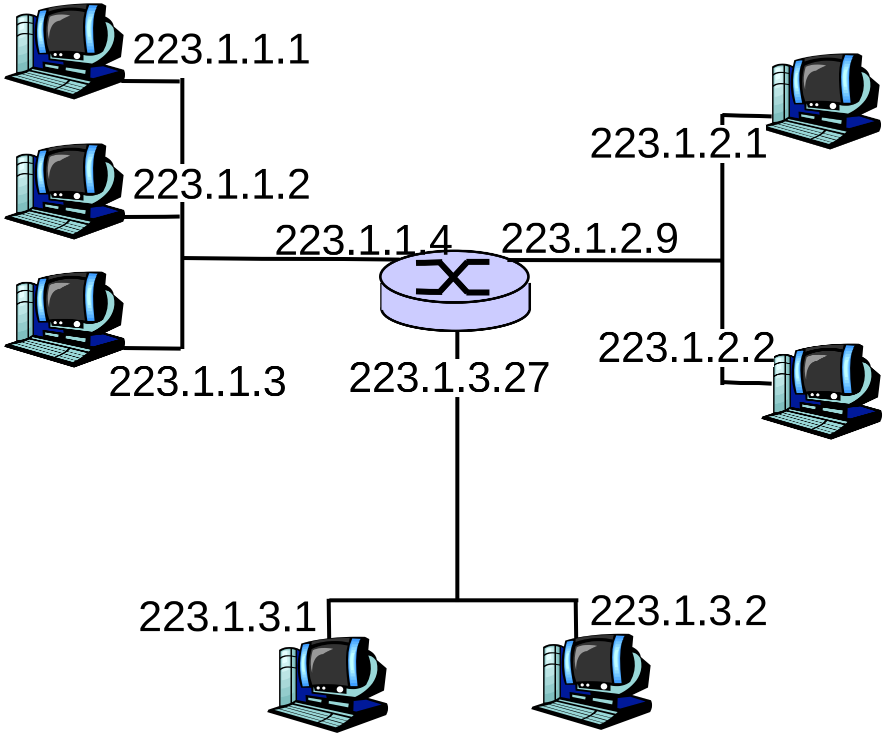
- Suppose A and B have been assigned the same IP address on the same Ethernet, on which ARP is used. B starts up after A.
    - How can A guard against this?
    - A might monitor for ARP broadcasts purportedly coming from itself.
    - A might even immediately follow such broadcasts with its own ARP broadcast in order to return its traffic to itself.

Exercise (Peterson & Davie, 5th ed.)

- Suppose A and B have been assigned the same IP address on the same Ethernet, on which ARP is used. B starts up after A.
  - Explain how “self-ARP” (querying the network on start-up for one’s own IP address) might help with this problem.
  - If B uses self-ARP on startup, it will receive a reply indicating that its IP address is already in use
  - This is a clear indication that B should not continue on the network until the issue is resolved.

IP Addressing: introduction

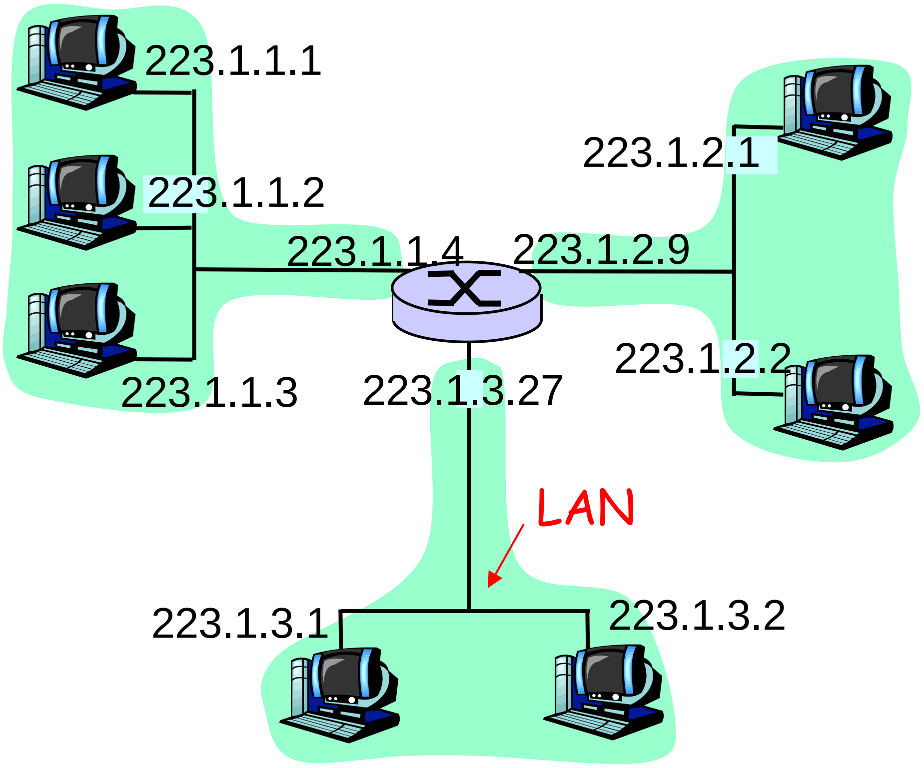
- IP address: 32-bit identifier for host or router *interface*
- *interface:* connection between host/router and physical link
    - router's typically have multiple interfaces
    - a host has typically a single interface
    - IP addresses associated with interface, not host, or router



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

IP Addressing

- IP address is divided into two parts:
  - network prefix
    - K high order bits
  - host number
    - remaining low order bits
- This partitioning of the address depends on the context network in which we see this NIC
  - networks are nested inside each other

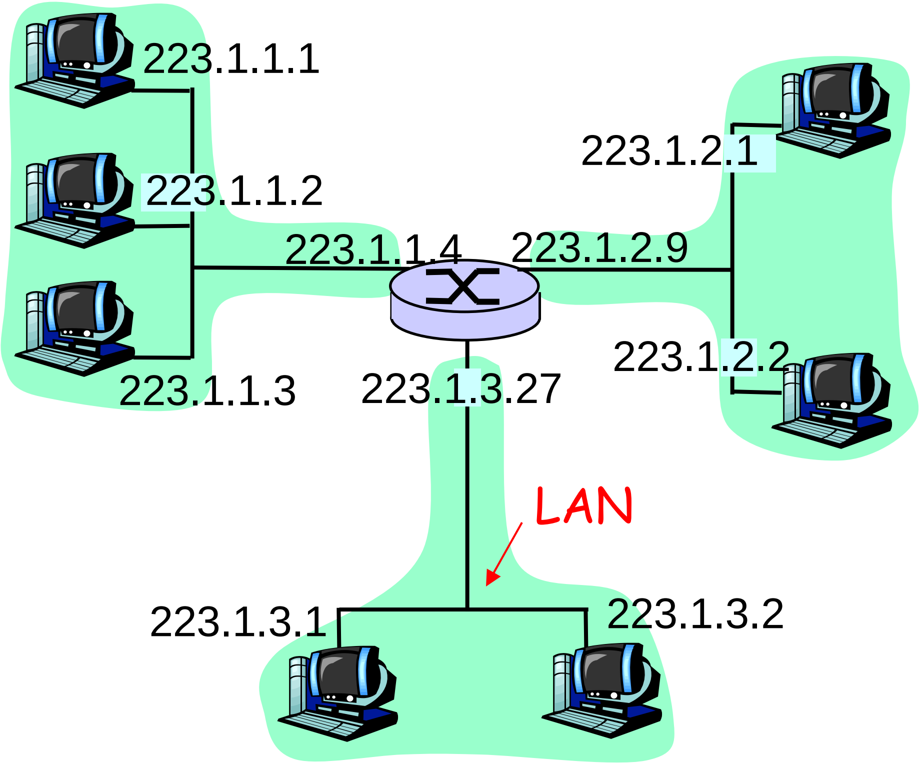


Qn: What is the router's IP address in the drawing we see?

What is a network in IP view?

IP network terminology:

- *a Subnet is:*
  - a set of devices that can physically reach each other without intervening router(s)
  - e.g. a LAN
- a Network is:
  - a subnet , or:
  - the union of several subnets that are interconnected by links



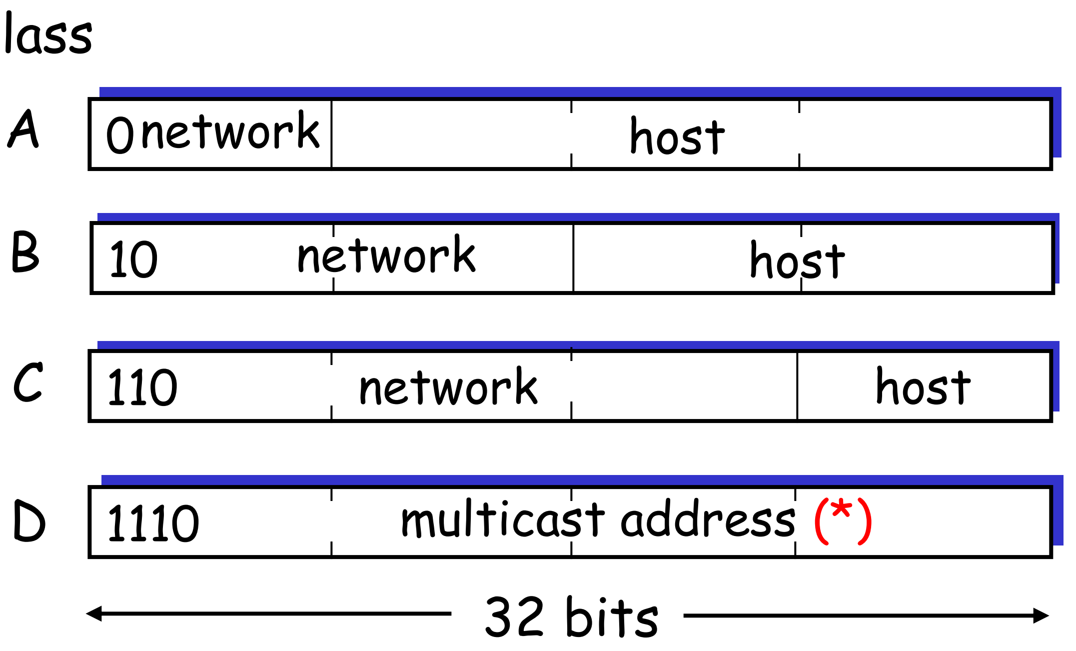
three subnets (LANs) 223.1.1.*, 223.1.2.*, 223.1.3.*, together they form a larger network with prefix 223.1 (16 bits) **(OR MORE bits?)**

IP Addresses

given notion of “network”, let’s re-examine IP addresses:

“classful” addressing:

(does not need mask or /K indicator)

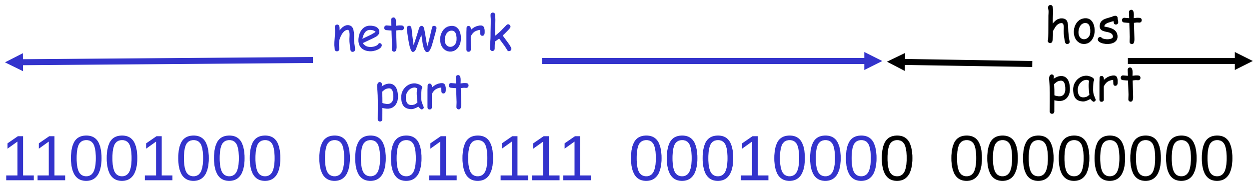


class	range
A	1.0.0.0 to 127.255.255.255
B	128.0.0.0 to 191.255.255.255
C	192.0.0.0 to 223.255.255.255
D	224.0.0.0 to 239.255.255.255

(*) this range used as multicast also in CIDR method

IP addressing: CIDR

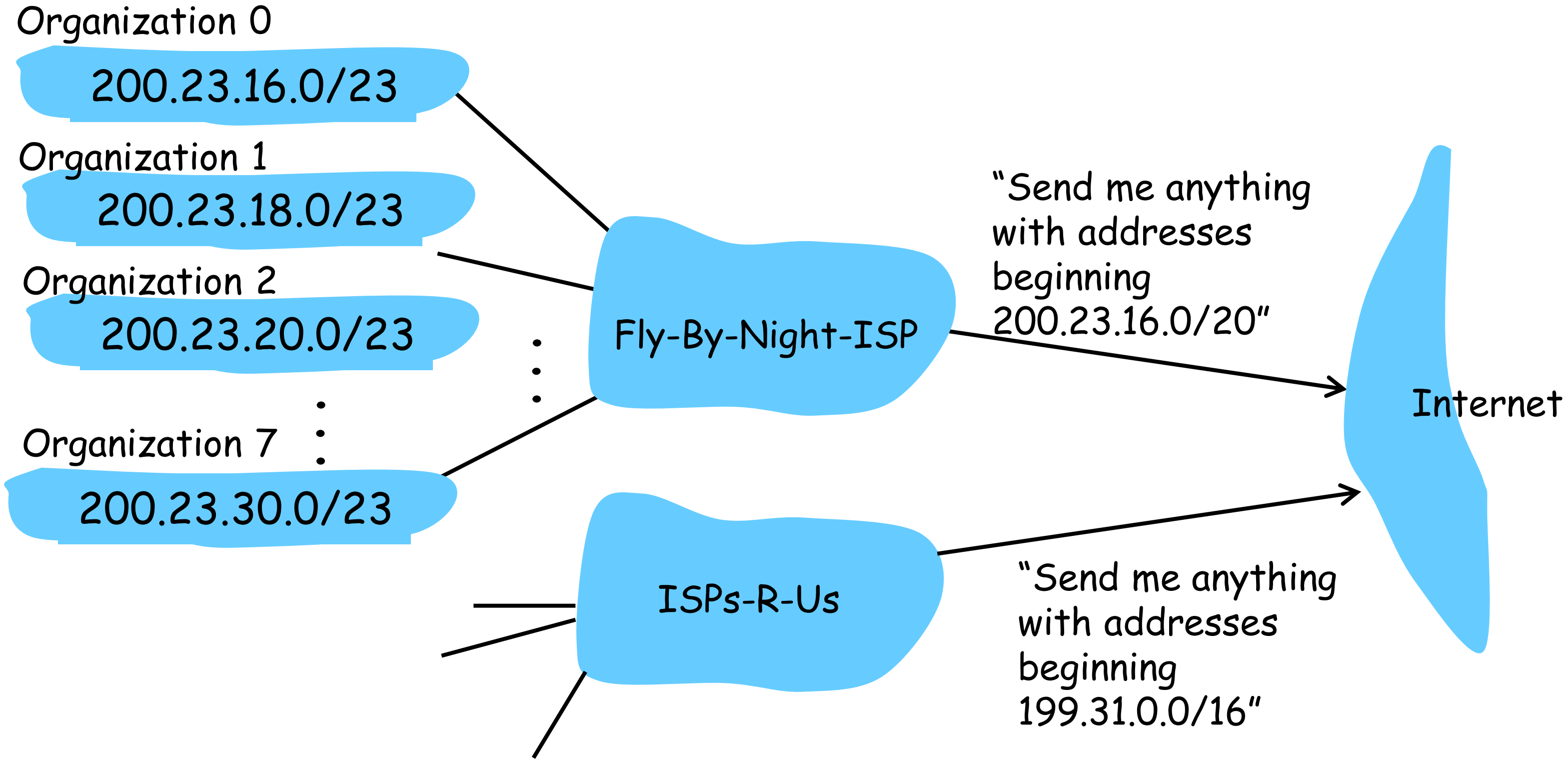
- classful addressing:
  - inefficient use of address space, address space exhaustion
  - e.g., class B net allocated enough addresses for 65K hosts, even if only 2K hosts in that network
- CIDR: Classless InterDomain Routing
  - network portion of address of arbitrary length
  - address format: a.b.c.d/x, where x is # bits in network portion of address
  - Requires inclusion of mask or "/K" in routing table



200.23.16.0/23

Hierarchical addressing: route aggregation

Hierarchical addressing allows efficient advertisement of routing information:

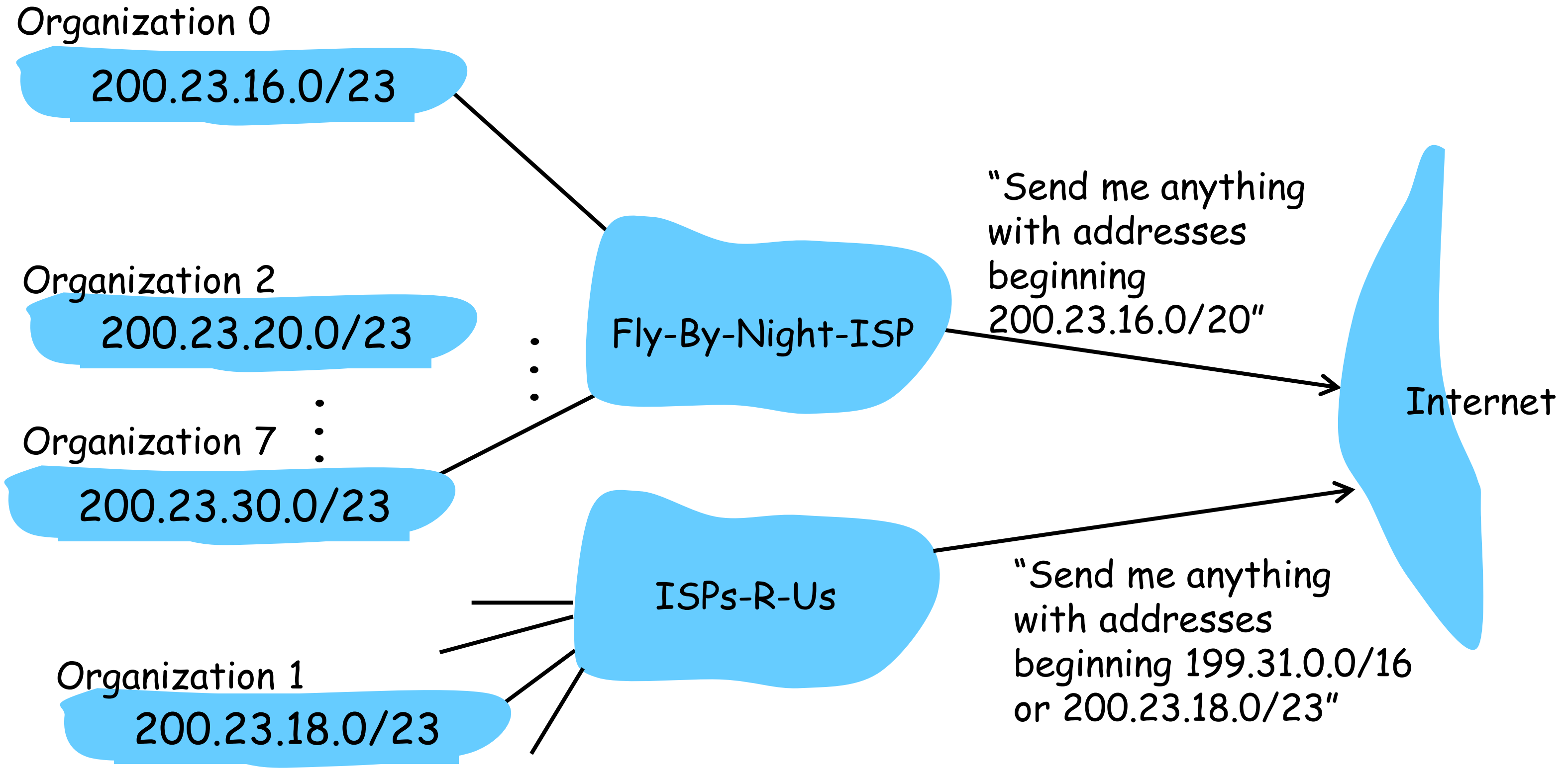


"Send me anything with addresses beginning 200.23.16.0/20"

"Send me anything with addresses beginning 199.31.0.0/16"

Hierarchical addressing: more specific routes

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



"Send me anything with addresses beginning 200.23.16.0/20"

"Send me anything with addresses beginning 199.31.0.0/16 or 200.23.18.0/23"

Print the routing table

- `Windows: “route print”`
- `Linux: “netstat -rn“`

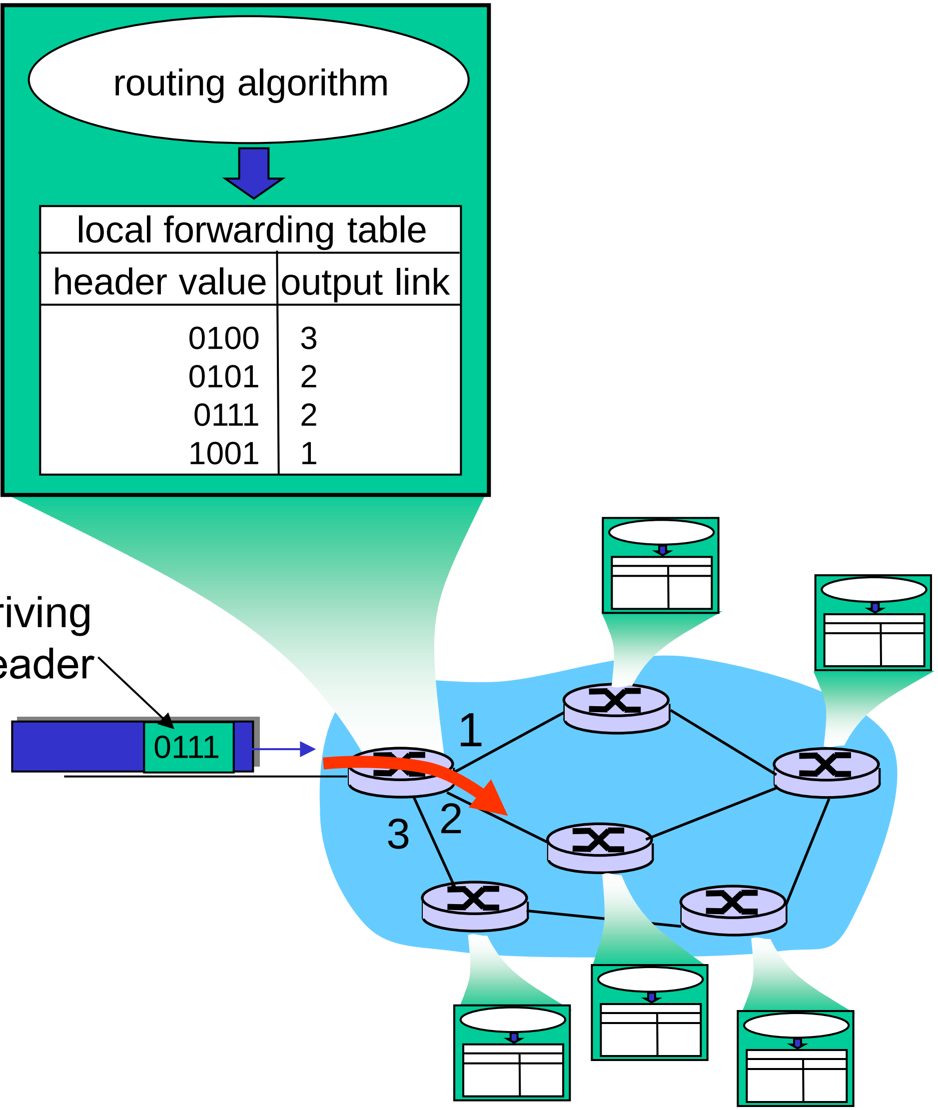
- On nova.cs.tau.ac.il (132.67.192.133) this gives:

```
nova 2% netstat -rn
Kernel IP routing table
Destination     Gateway         Genmask         Flags   MSS Window  irtt Iface
132.67.192.0    0.0.0.0         255.255.255.0   U         0 0          0 eth0
0.0.0.0         132.67.192.1    0.0.0.0         UG        0 0          0 eth0
```

Extra slides

Review of lecture, if time permits

Interplay between routing and forwarding



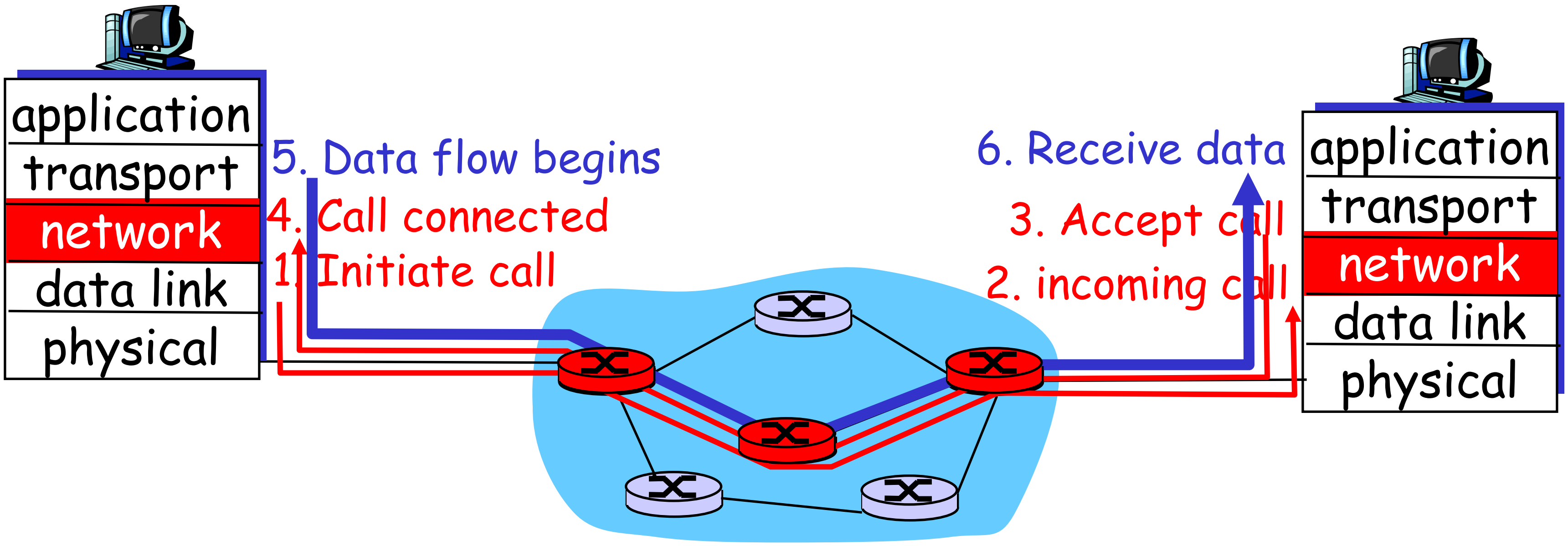
local forwarding table

header value	output link
0100	3
0101	2
0111	2
1001	1

value in arriving packet's header

Virtual circuits: signaling protocols

- used to setup, maintain teardown VC
- used in ATM, frame-relay, X.25
- not used in today's Internet



IP addresses: how to get one?

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

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

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

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