

# Communication Networks (0368-3030) / Spring 2011

The Blavatnik School of Computer Science,  
Tel-Aviv University

Allon Wagner

A decorative graphic consisting of several horizontal lines of varying lengths and colors (teal, light blue, white) extending from the right side of the slide towards the center.

# Network Layer – Forwarding

Kurose & Ross, Chapter 4 (5<sup>th</sup> ed.)

Many slides adapted from:

J. Kurose & K. Ross \

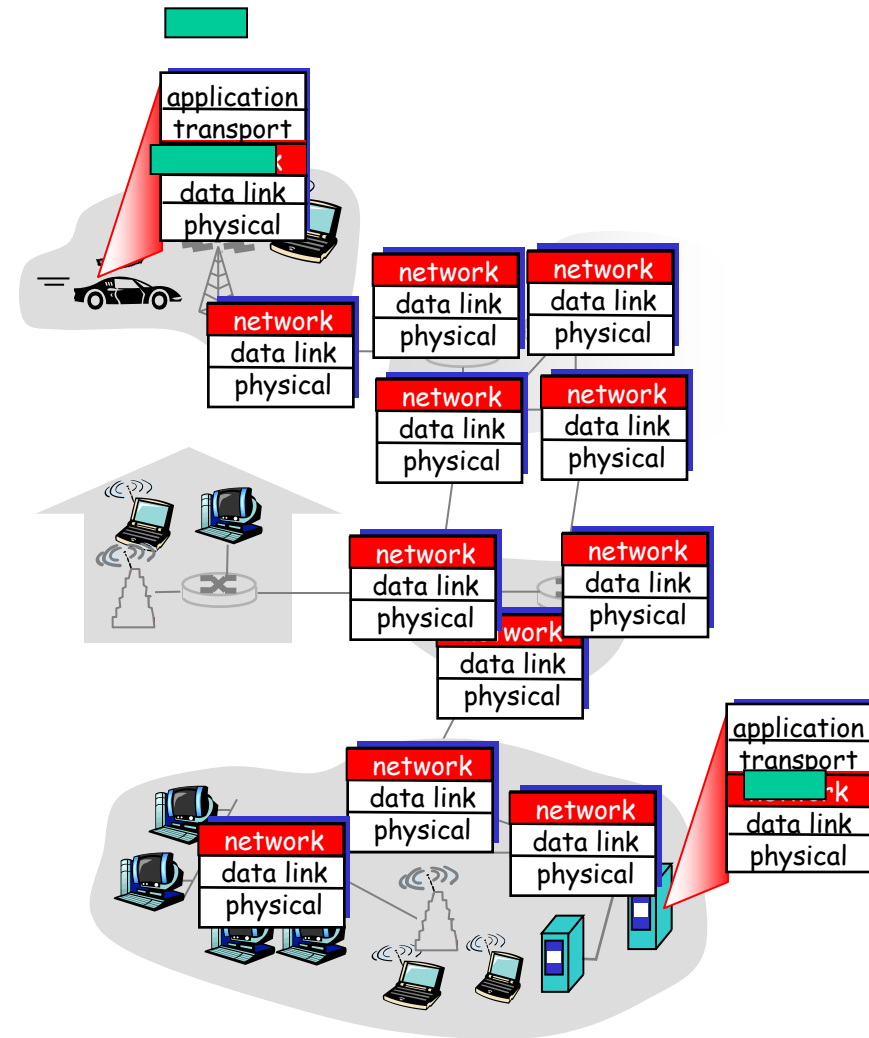
Computer Networking: A Top Down Approach (5<sup>th</sup> ed.)

Addison-Wesley, April 2009.

Copyright 1996-2010, J.F Kurose and K.W. Ross, All Rights Reserved.

# 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.

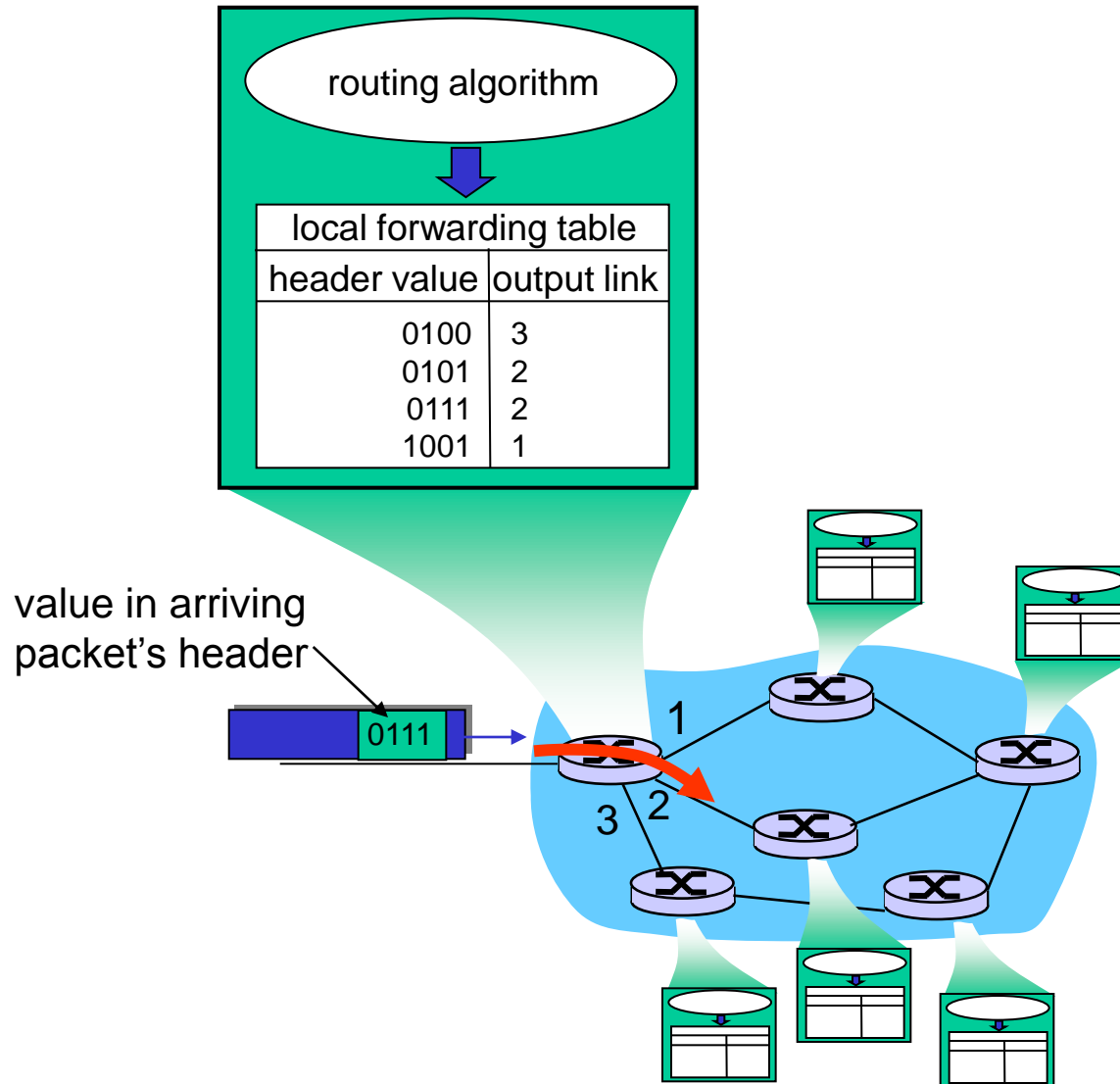
- *routing algorithms*

## analogy:

❖ *routing*: process of planning trip from source to dest

❖ *forwarding*: process of getting through single interchange

# Interplay between routing and forwarding



# 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)

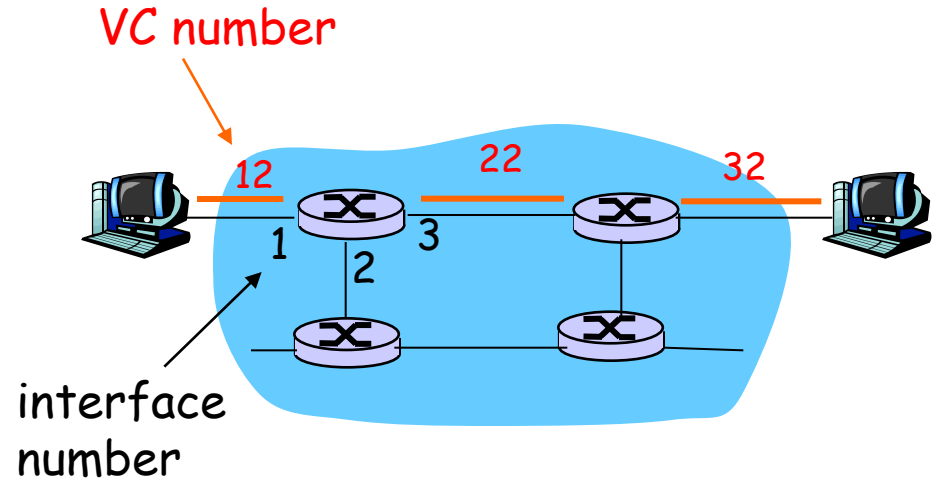


# VC implementation

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



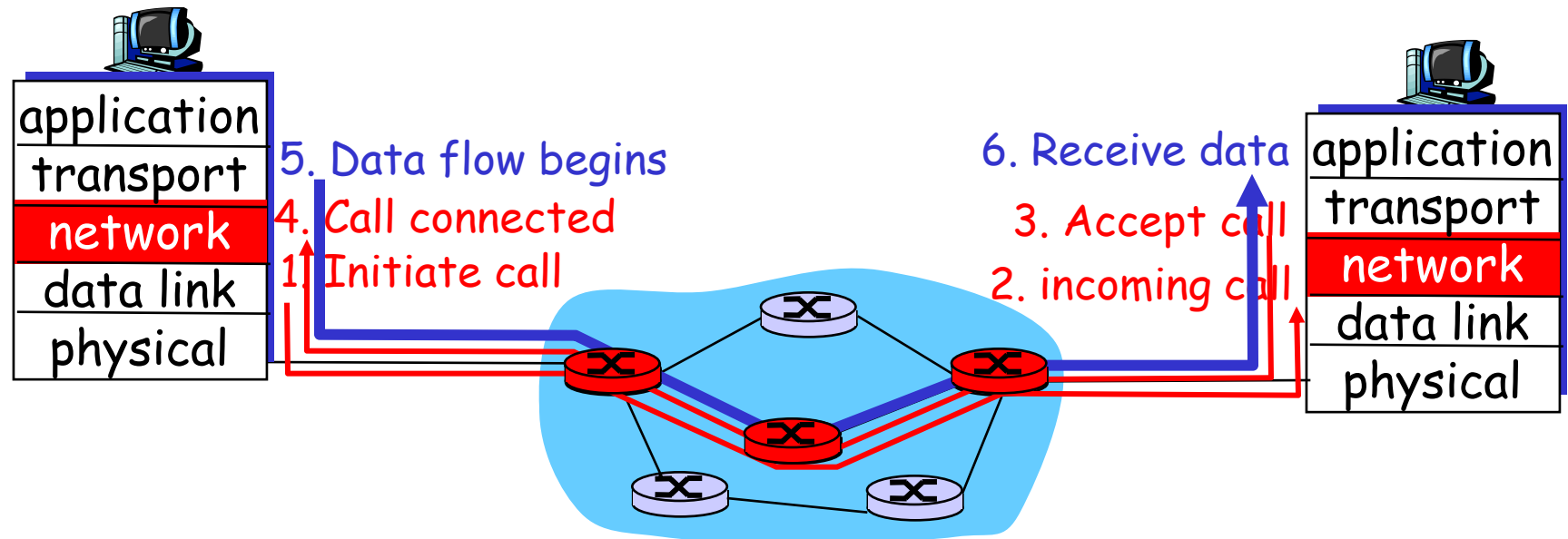
Forwarding table in northwest router:

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!**

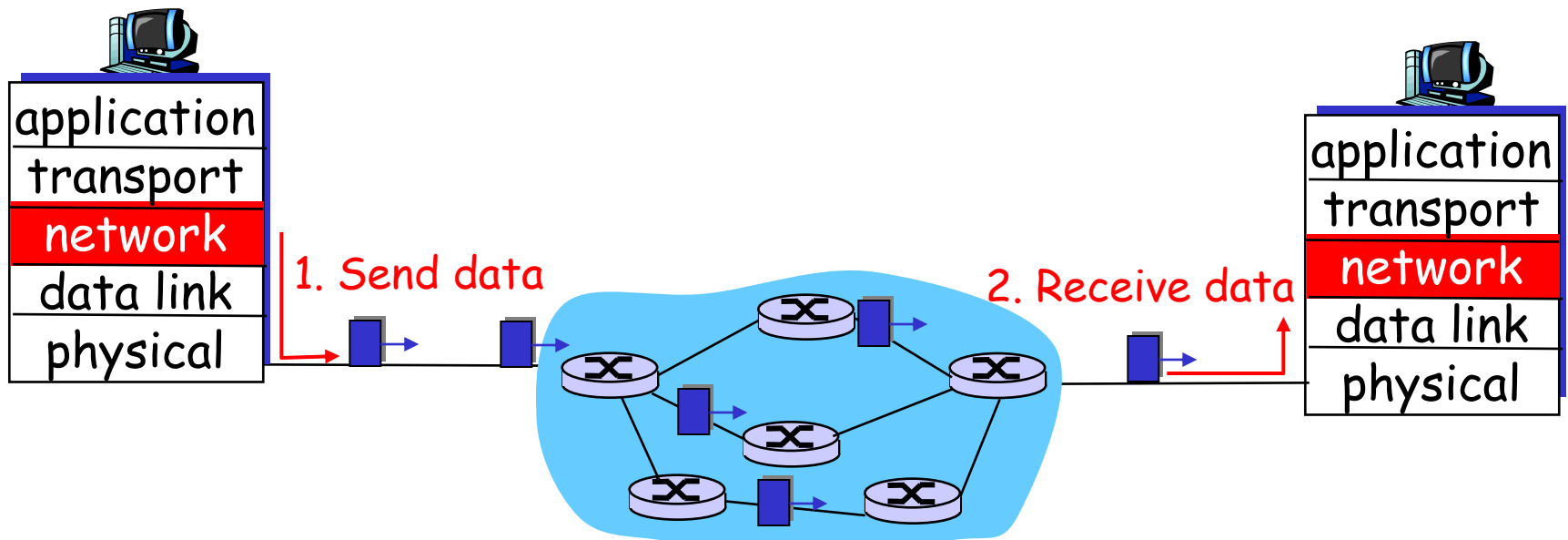
# Virtual circuits: signaling protocols

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



# 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)

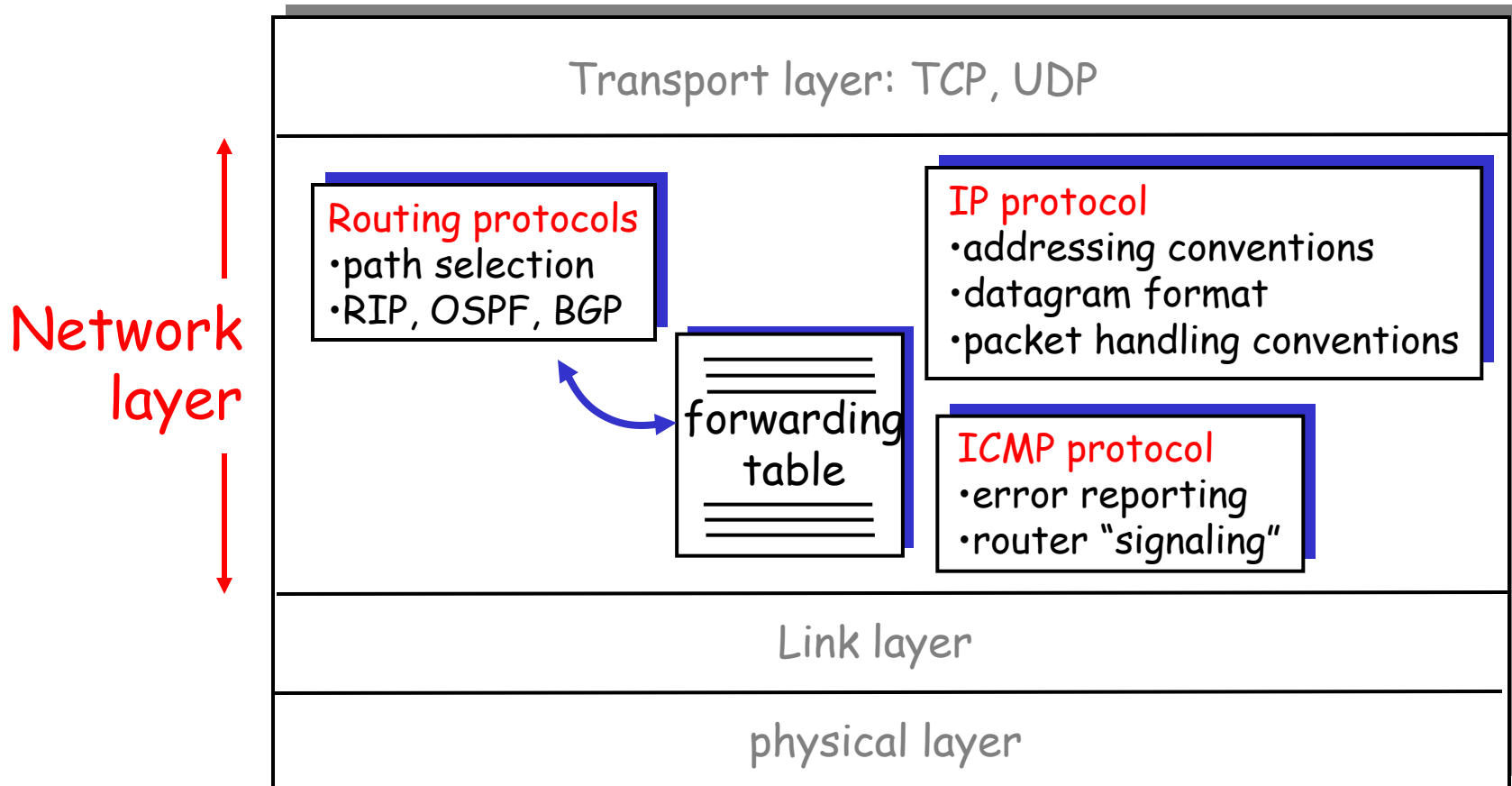
- ❖ data exchange among computers
  - “elastic” service, no strict timing req.
- ❖ “smart” end systems (computers)
  - can adapt, perform control, error recovery
  - simple inside network, complexity at “edge”
- ❖ many link types
  - different characteristics
  - uniform service difficult

## 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:



# IP datagram format

IP protocol version number

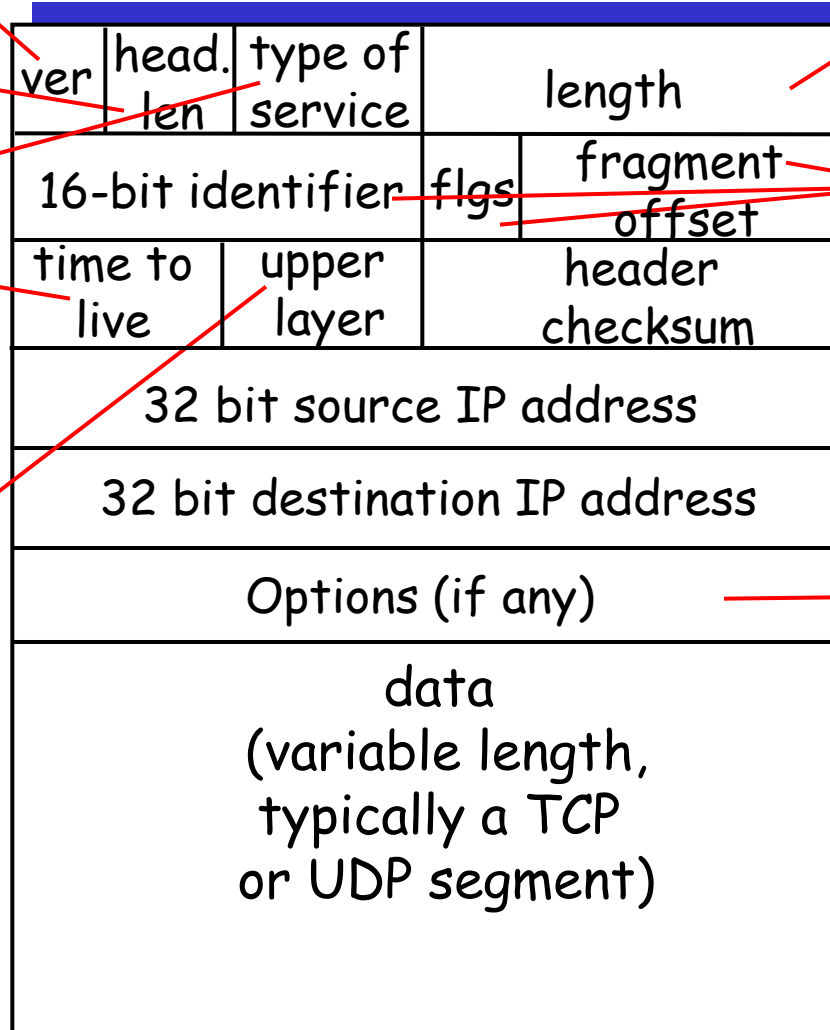
header length (bytes)

"type" of data

max number remaining hops (decremented at each router)

upper layer protocol to deliver payload to

← 32 bits →



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

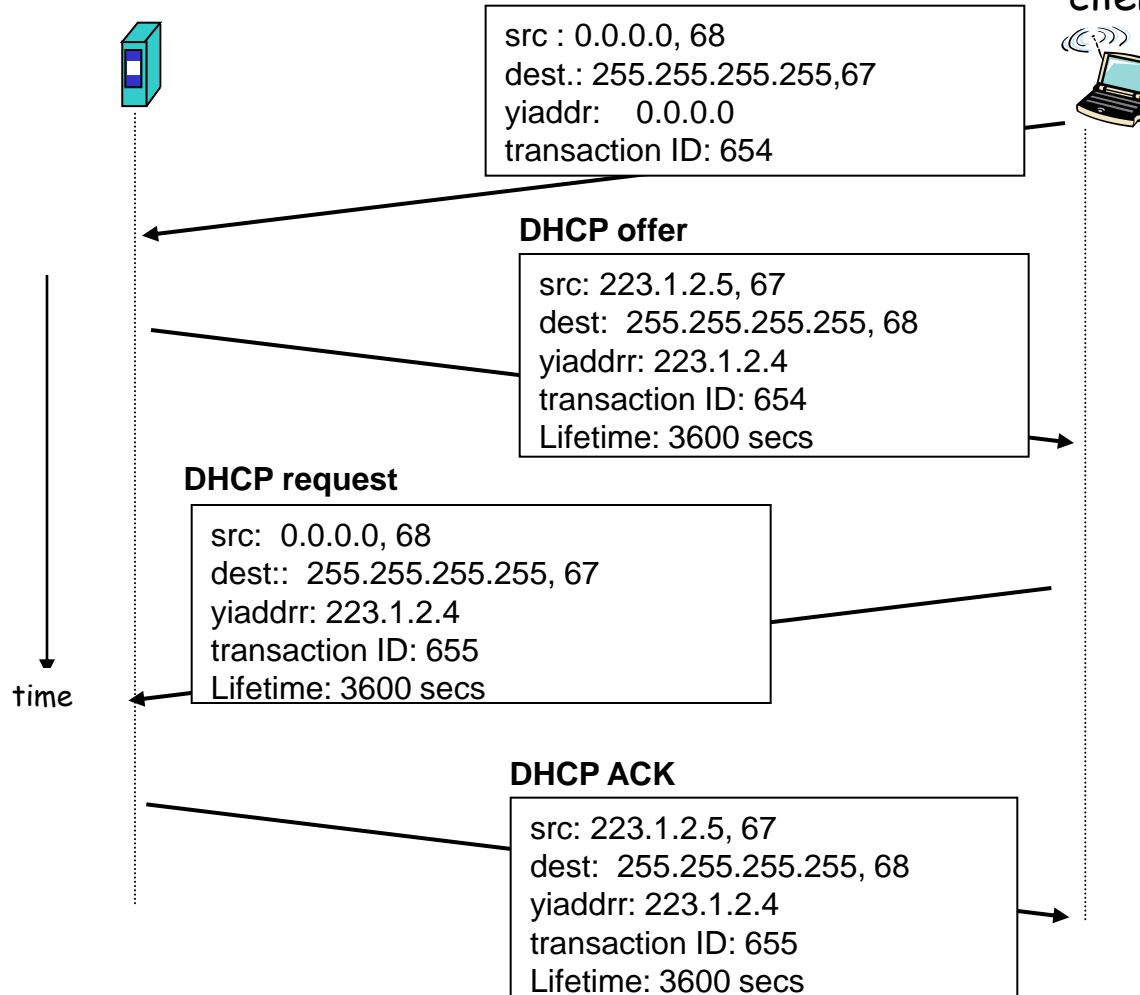
- How can a newly connected host get an IP address?
  - (And other useful information: its network mask, an IP address of DNS server etc.)
  - Manual configuration by a system administrator
  - DHCP
    - Plug and play – host obtains this information automatically
    - Defined in RFCs 2131 & 2132.
    - 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 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

<u>Type</u>	<u>Code</u>	<u>description</u>
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

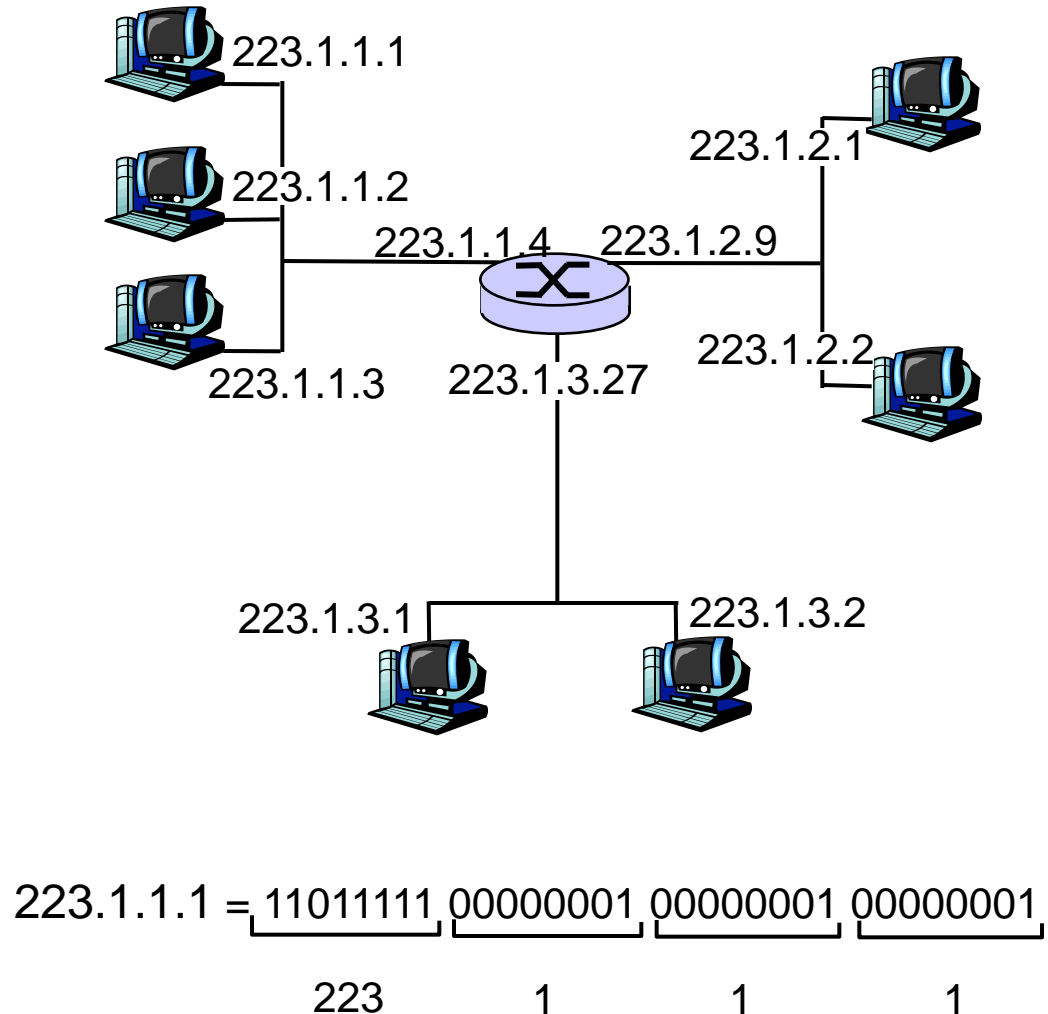
- ❖ UDP segment eventually arrives at destination host
- ❖ destination returns ICMP "port unreachable" packet (type 3, code 3)
- ❖ when source gets this ICMP, stops.

# Extra slides

Review of lecture, if time permits

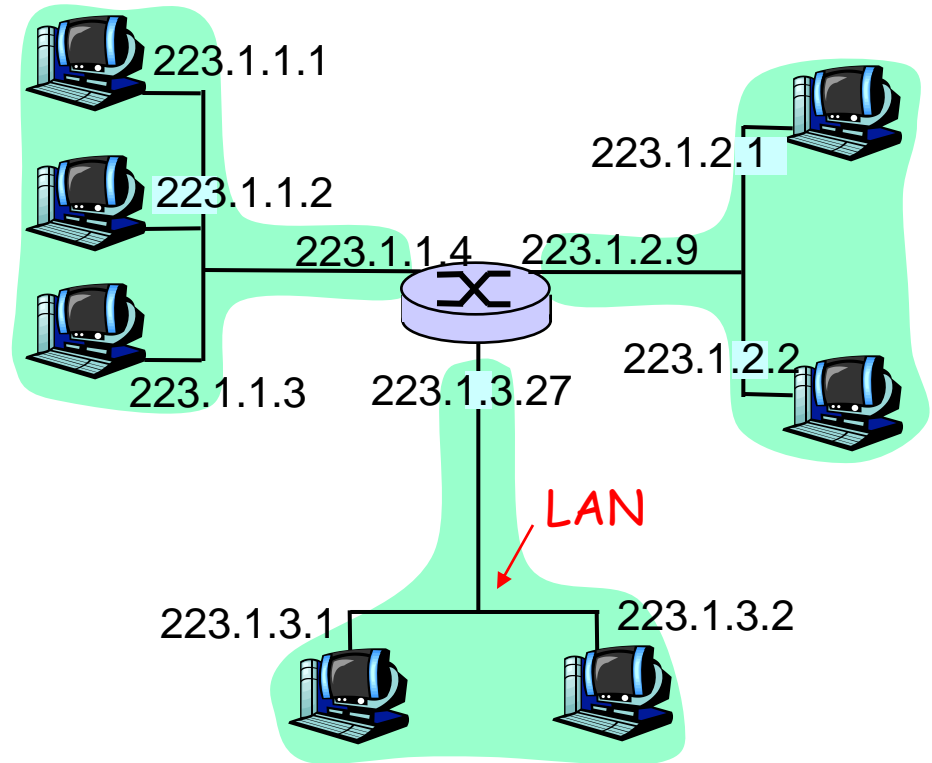
# IP Addressing: introduction

- ❖ 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



# 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?

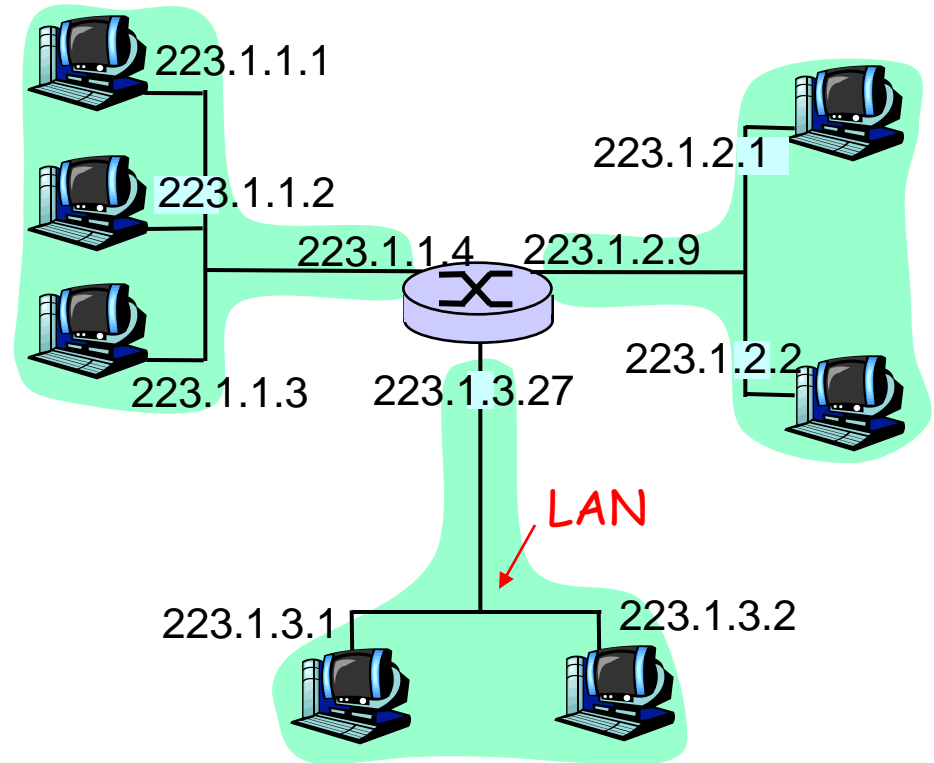
## IP network terminology:

### ❖ *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



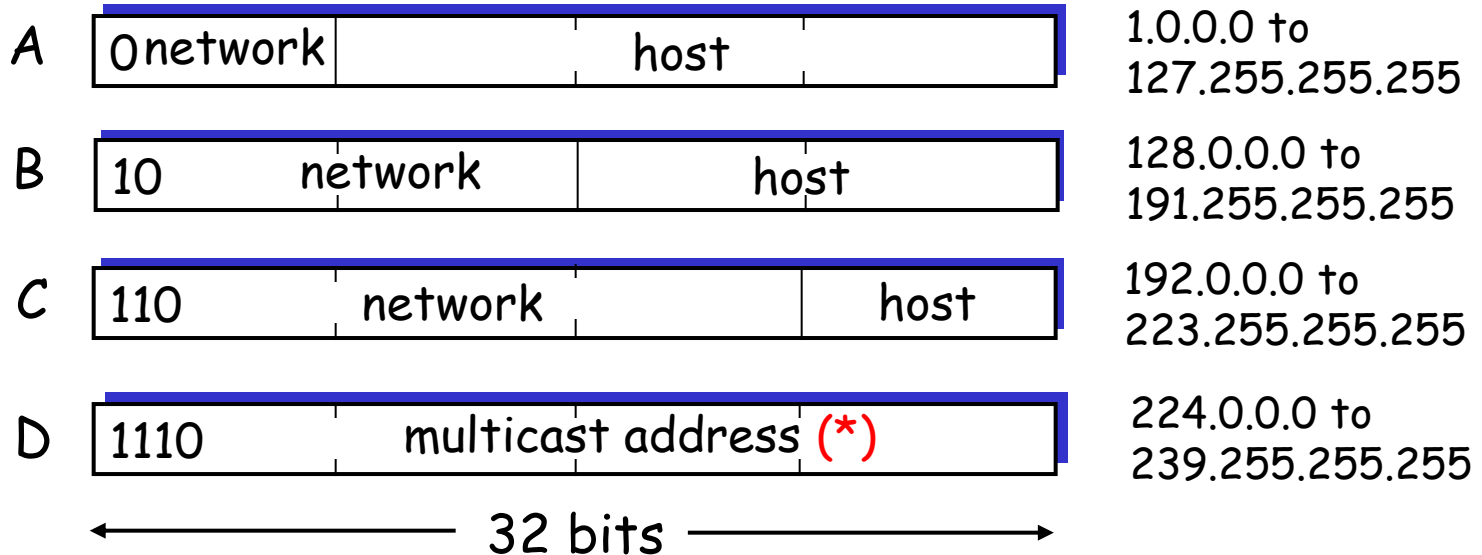
three subnets (LANs) 223.1.1.\*, 223.1.2.\*, 223.1.3.\*, together they form a larger network with prefix 223.1 (16 bits) (OR MORE bits?)

# IP Addresses

given notion of "network", let's re-examine IP addresses:

"classful" addressing:  
(does not need mask or /K indicator)

class



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

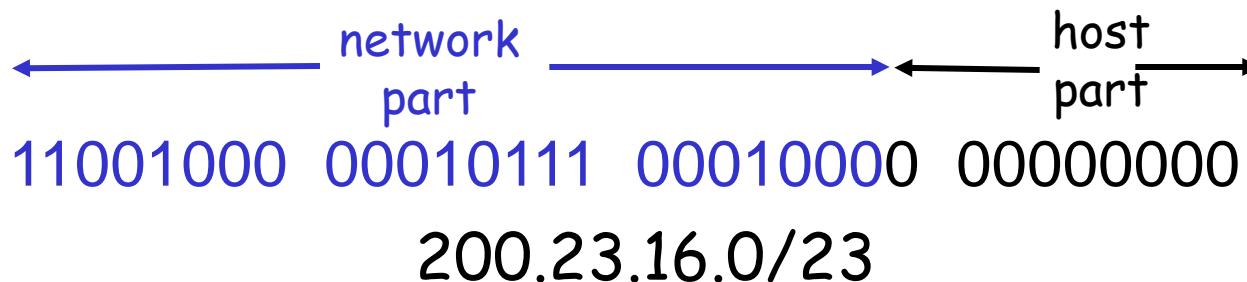
# IP addressing: CIDR

## ❖ 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**

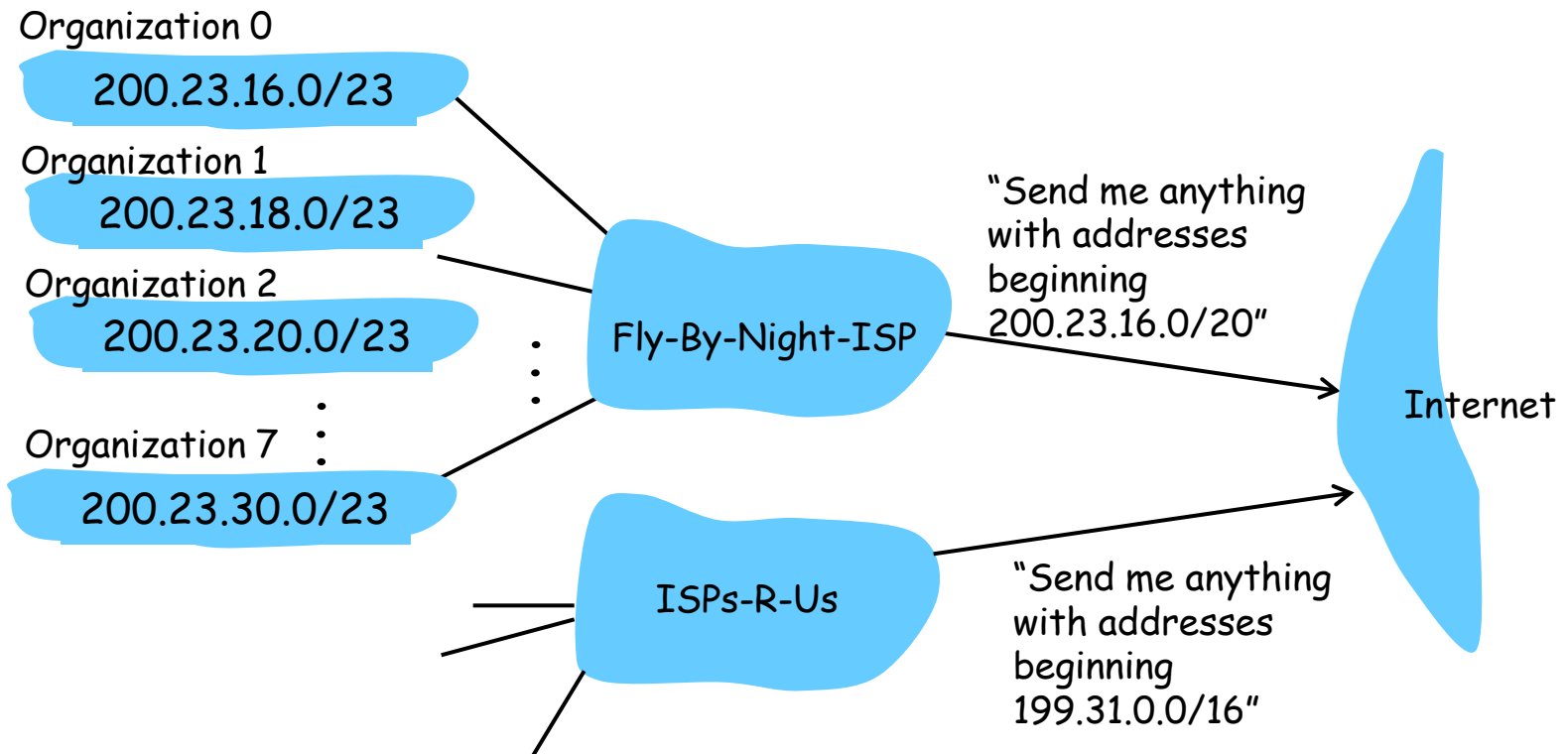
- network portion of address of arbitrary length
- address format: **a.b.c.d/x**, where x is # bits in network portion of address
- Requires inclusion of mask or "/K" in routing table





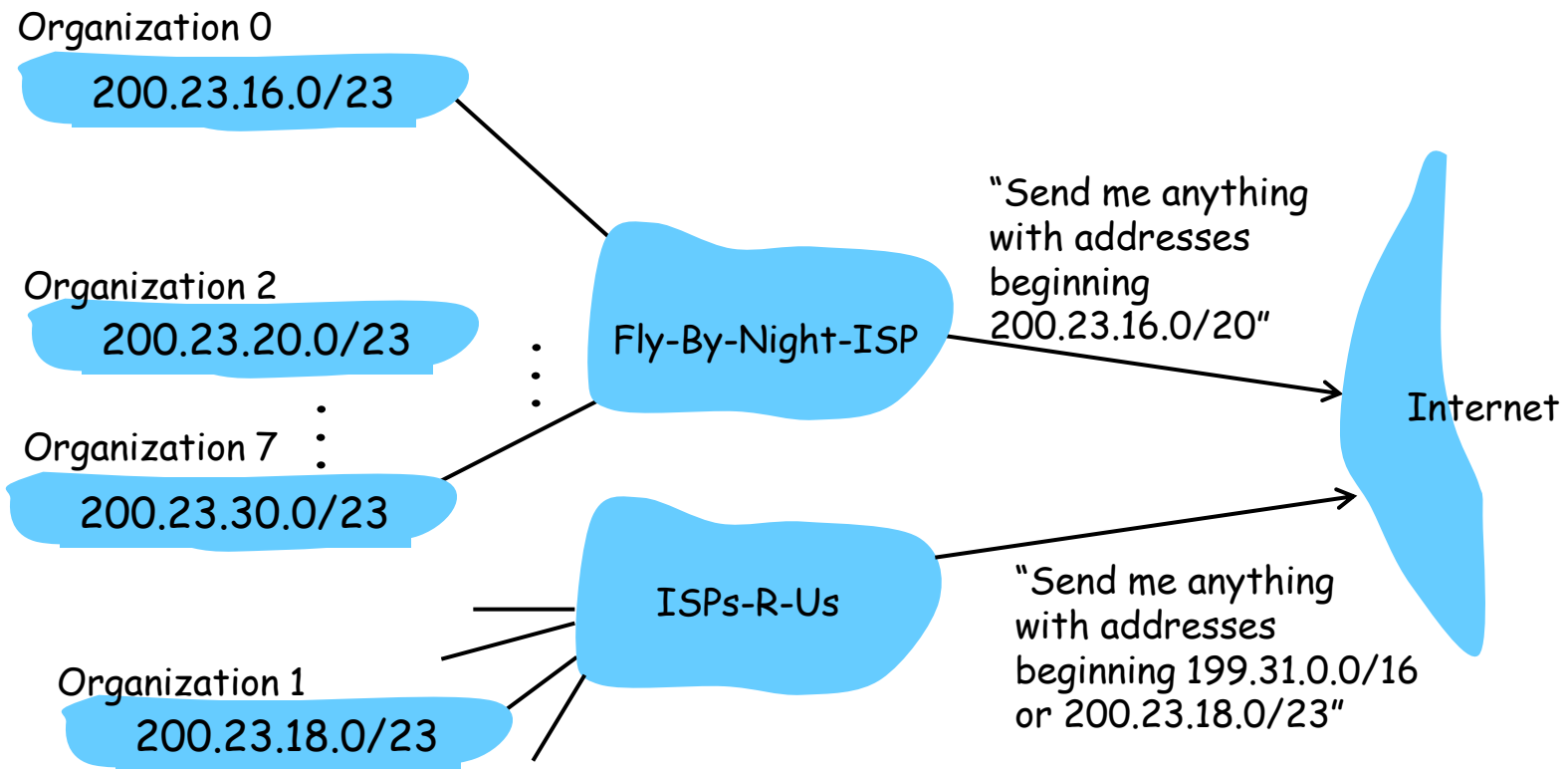
# Hierarchical addressing: route aggregation

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 *network* get subnet part of IP addr?

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

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

## IP addressing: the last word...

Q: How does an ISP get block of addresses?

A: **ICANN:** Internet **C**orporation for **A**ssigned  
**N**ames and **N**umbers

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