

Chapter 4

Network Layer:

The Data Plane

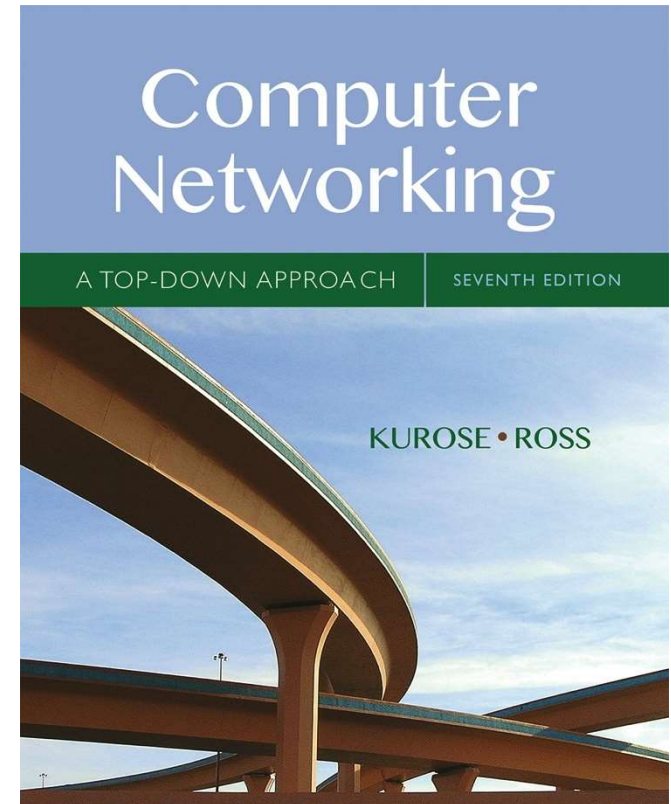
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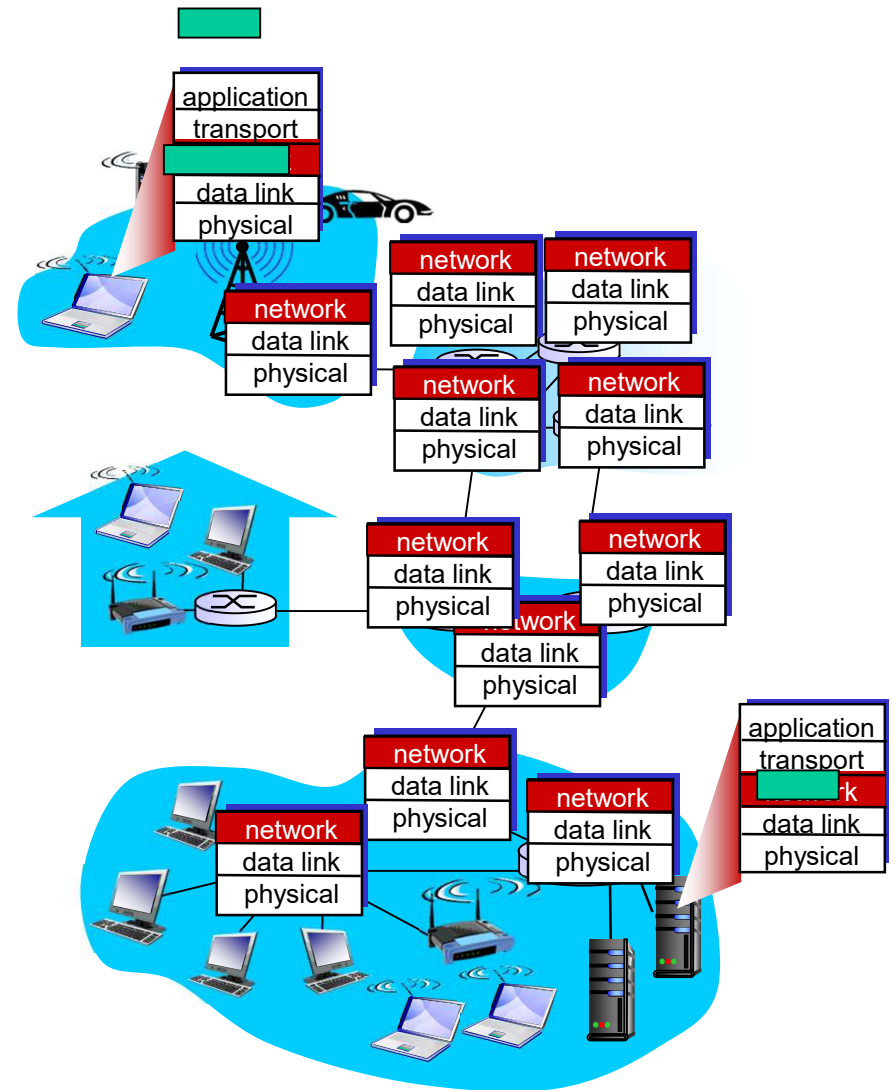
Computer Networking: A Top Down Approach

7th edition

Jim Kurose, Keith Ross
Pearson/Addison Wesley
April 2016

Network layer

- transport segment from sending to receiving host
- on sending side encapsulates segments into datagrams
- 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 network-layer functions

network-layer functions:

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

analogy: taking a trip

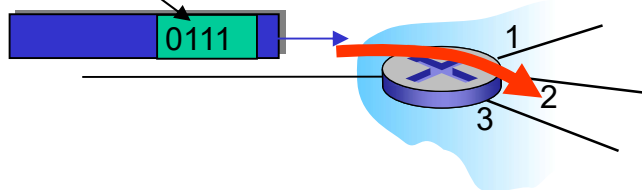
- *forwarding*: process of getting through single interchange
- *routing*: process of planning trip from source to destination

Network layer: data plane, control plane

Data plane

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

values in arriving
packet header



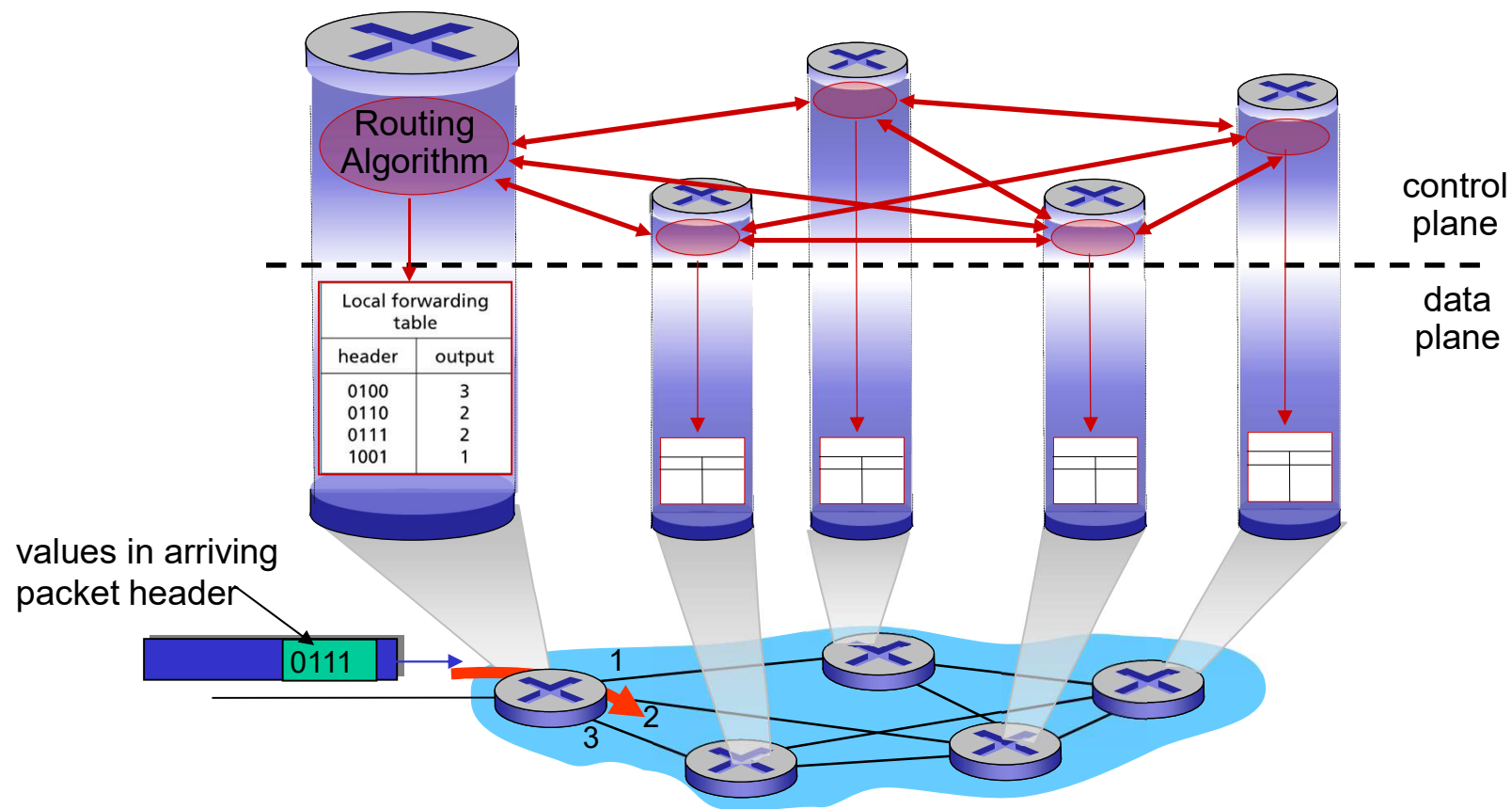
Control plane

- 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)*: implemented in (remote) servers

out-of-scope

Per-router control plane

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



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

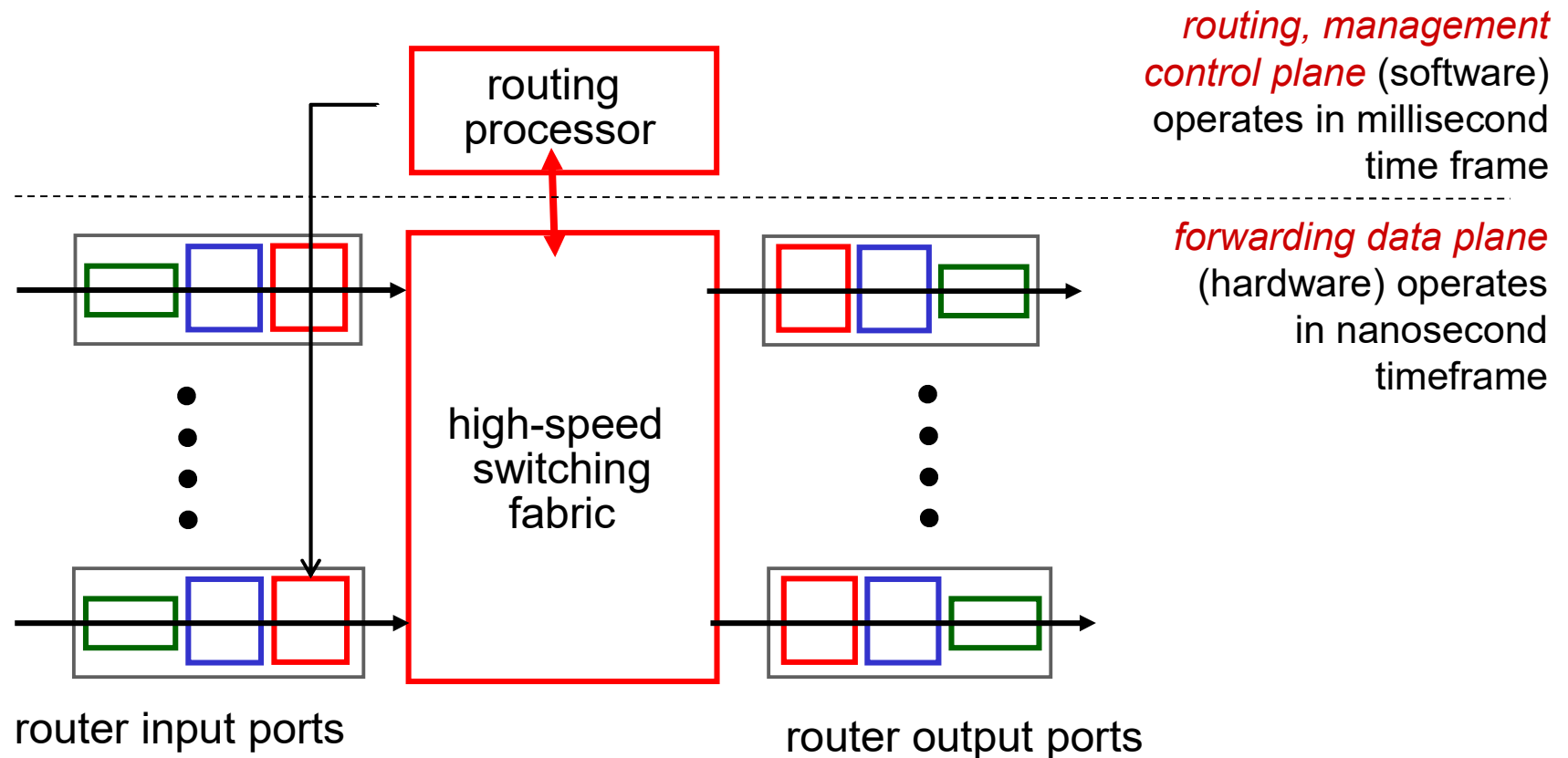
example services for a flow of datagrams:

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

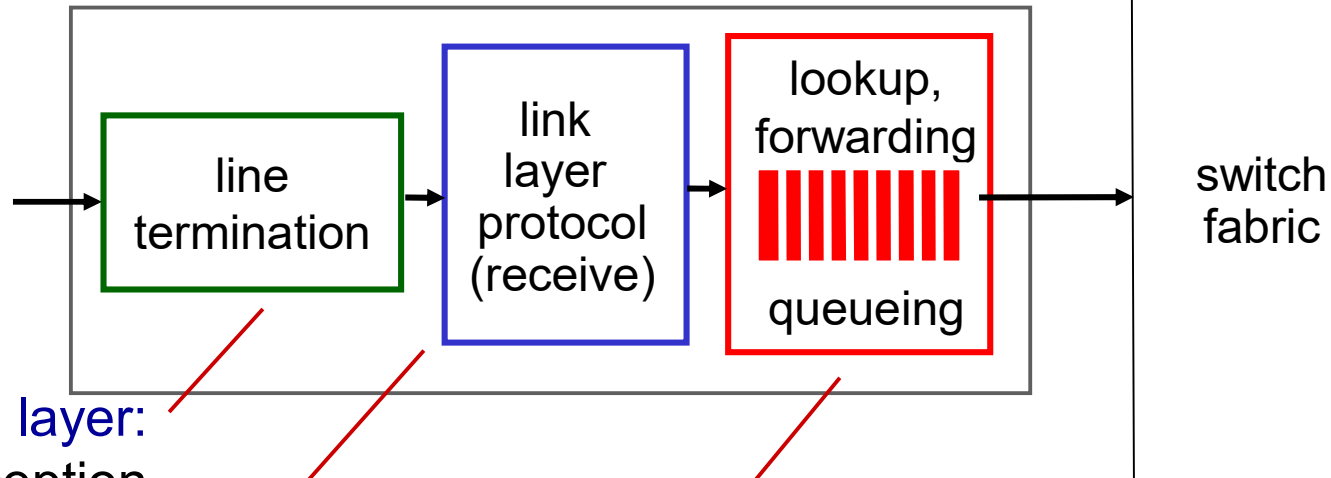
Internet: best effort (no guarantee on bandwidth, loss, ordering and timing)

Router architecture overview

- high-level view of generic router architecture:



Input port functions



physical layer:
bit-level reception

data link layer:
e.g., Ethernet
see chapter 5

decentralized switching:

- using header field values, lookup output port using forwarding table in input port memory (“*match plus action*”)
- *destination-based forwarding*: forward based only on destination IP address (traditional)
- *generalized forwarding*: forward based on any set of header field values

out-of-scope

Destination-based forwarding

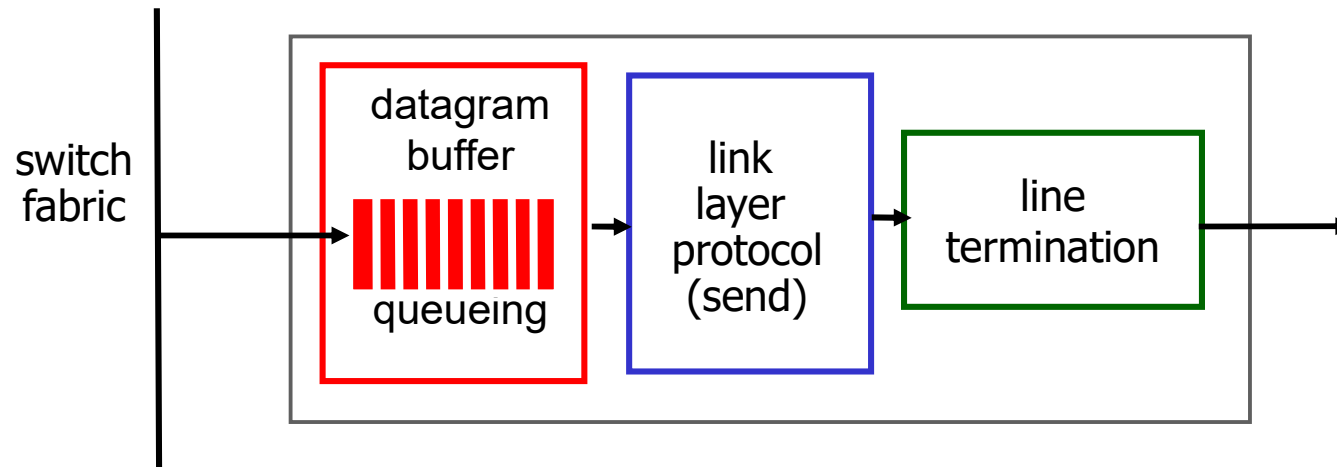
forwarding table

Destination Address Range	Link Interface
11001000 00010111 00010000 00000000 through 11001000 00010111 00010111 11111111	0
11001000 00010111 00011000 00000000 through 11001000 00010111 00011000 11111111	1
11001000 00010111 00011001 00000000 through 11001000 00010111 00011111 11111111	2
otherwise	3

Optimized method (longest prefix matching) explained later on

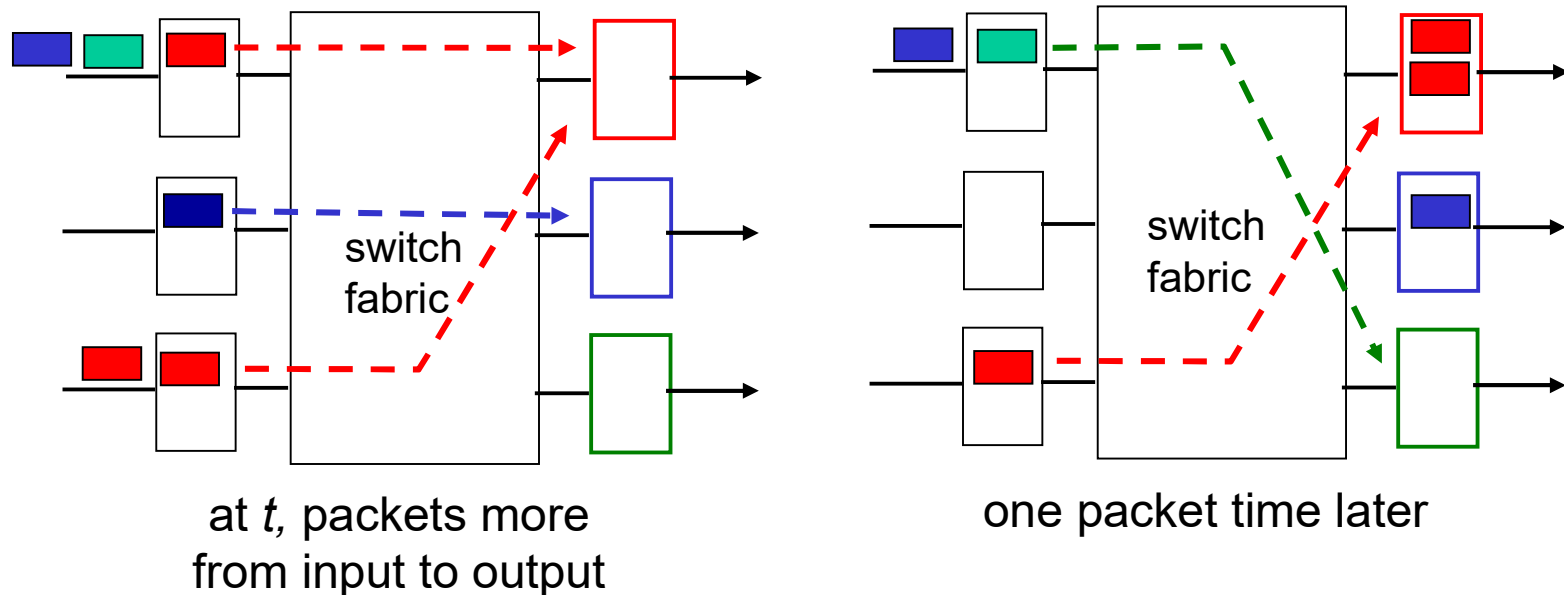
Output ports

This slide is HUGELY important!



- **buffering** required from fabric faster rate
Datagram (packets) can be lost due to congestion, lack of buffers
- **scheduling** datagrams
Priority scheduling – who gets best performance, network neutrality

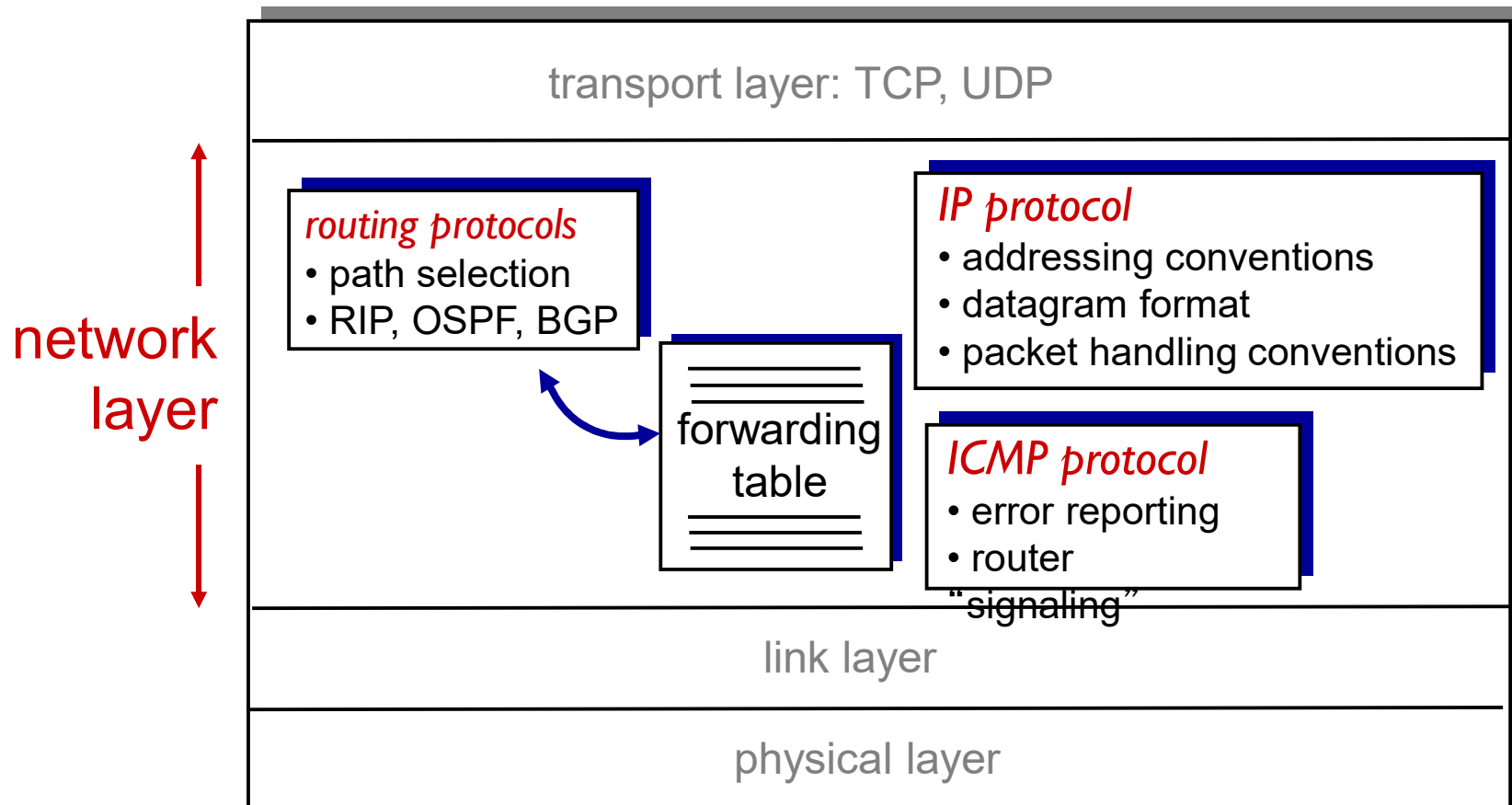
Output port queueing



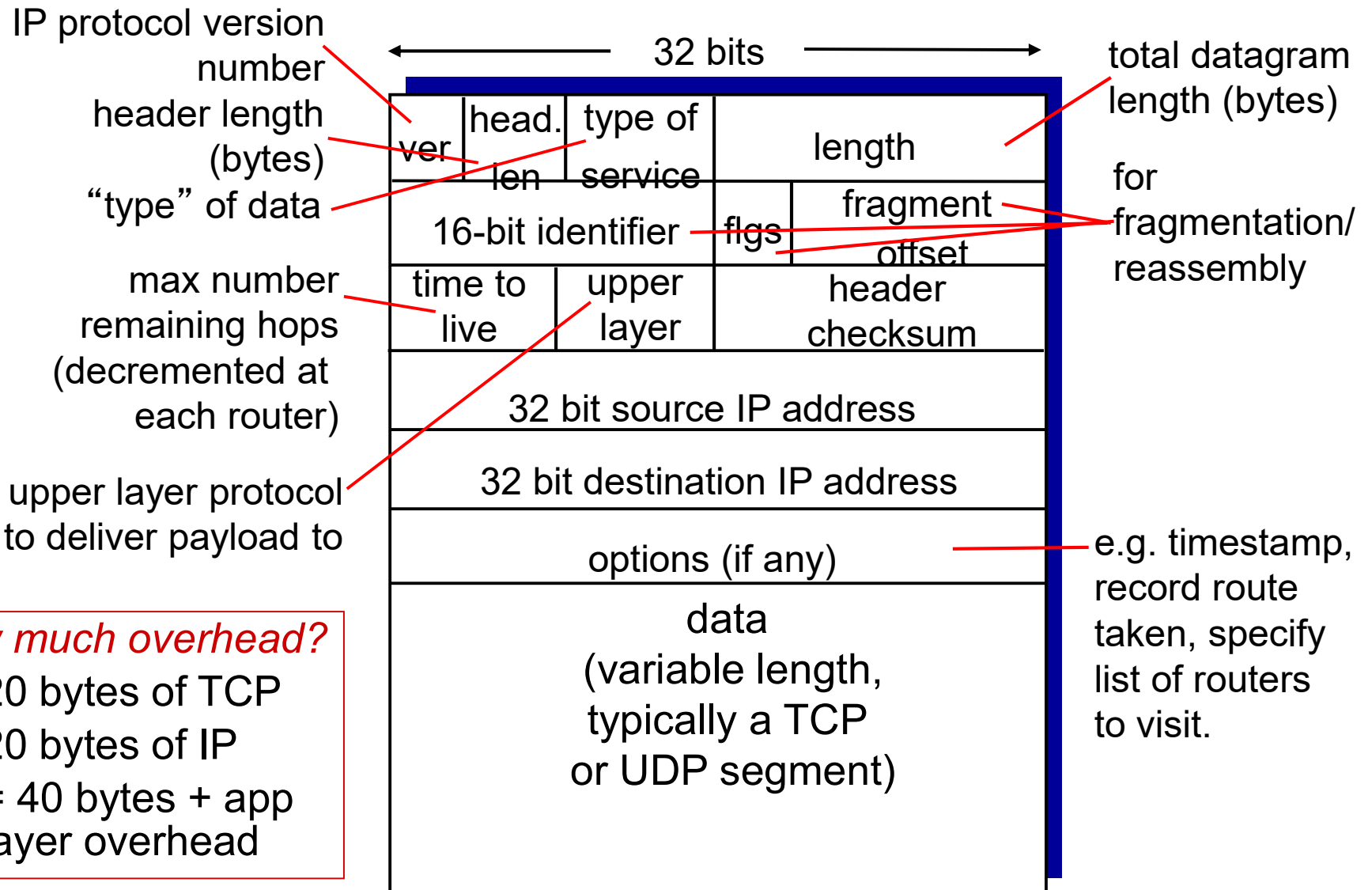
- buffering when arrival rate via switch exceeds output line speed
- *queueing (delay) and loss due to output port buffer overflow!*
- *output buffer service scheduling*

The Internet network layer

host, router network layer functions:



IP datagram format

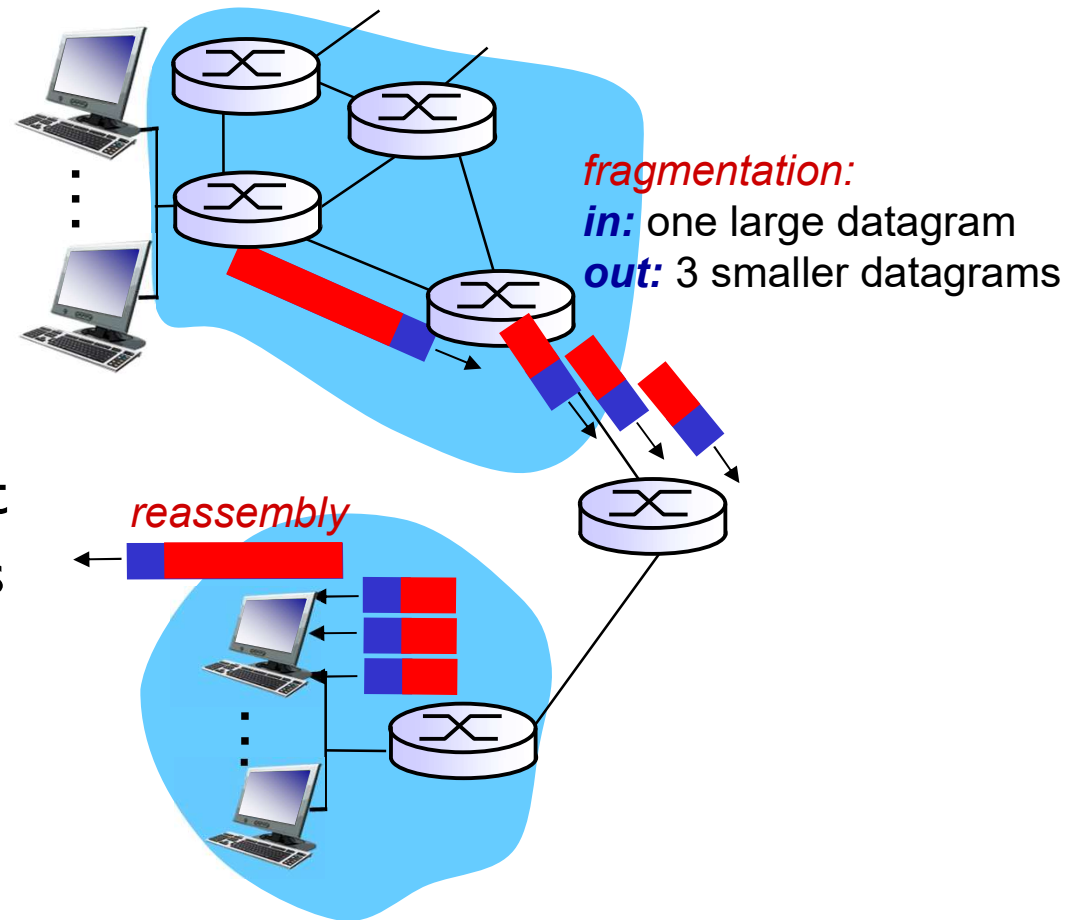


how much overhead?

- ❖ 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
- 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



IP fragmentation, reassembly

example:

- ❖ 4000 byte datagram
- ❖ MTU = 1500 bytes

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

*one large datagram becomes
several smaller datagrams*

1480 bytes in
data field

offset =
 $1480/8$

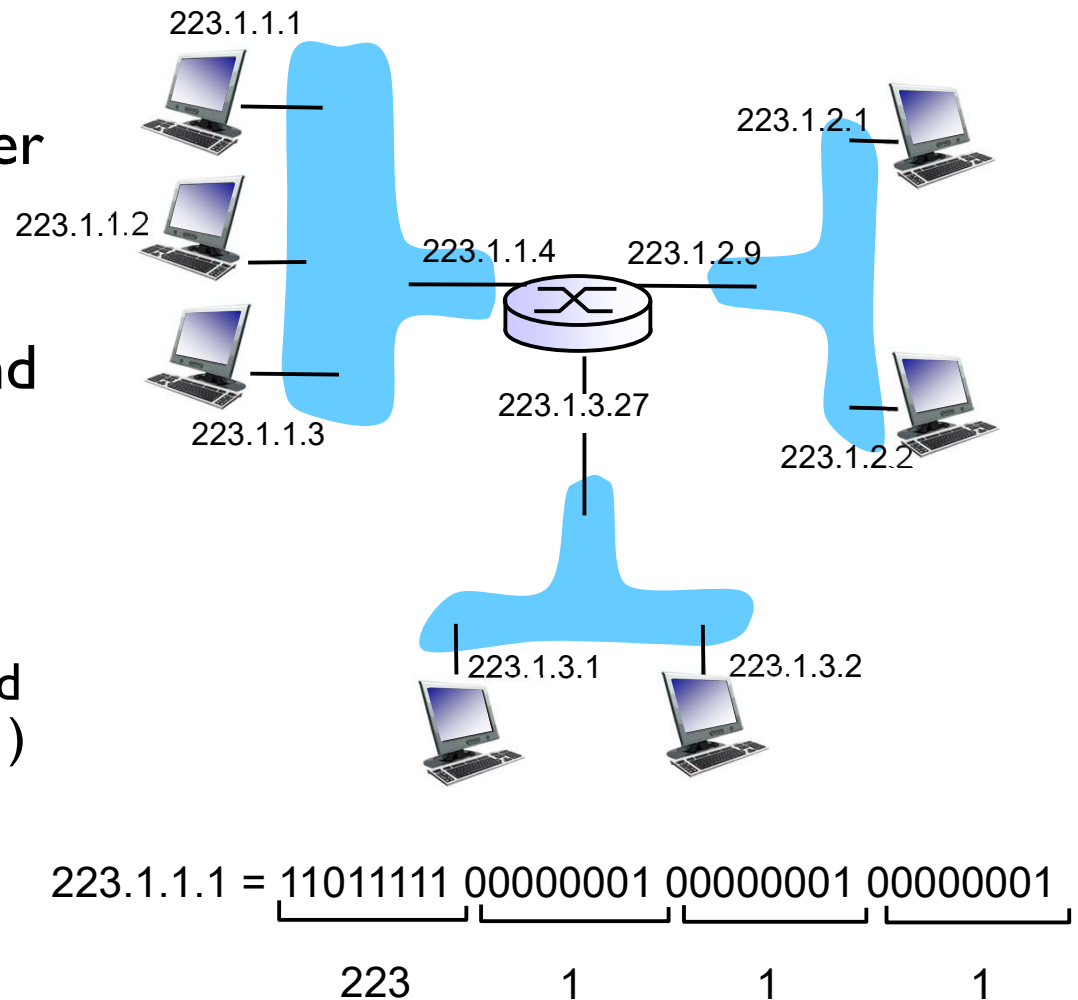
	length	ID	fragflag	offset	
	=1500	=x	=1	=0	

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

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

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**



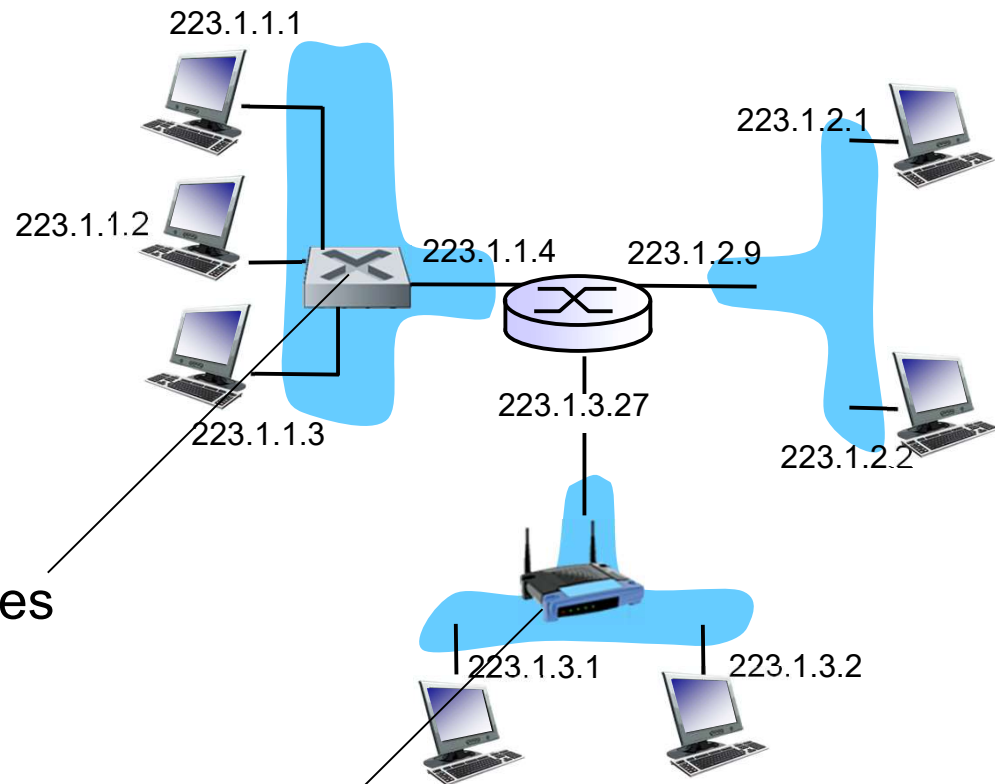
IP addressing: introduction

Q: how are interfaces actually connected?

A: we'll learn about that in chapter 5, 6.

A: wired Ethernet interfaces connected by Ethernet switches

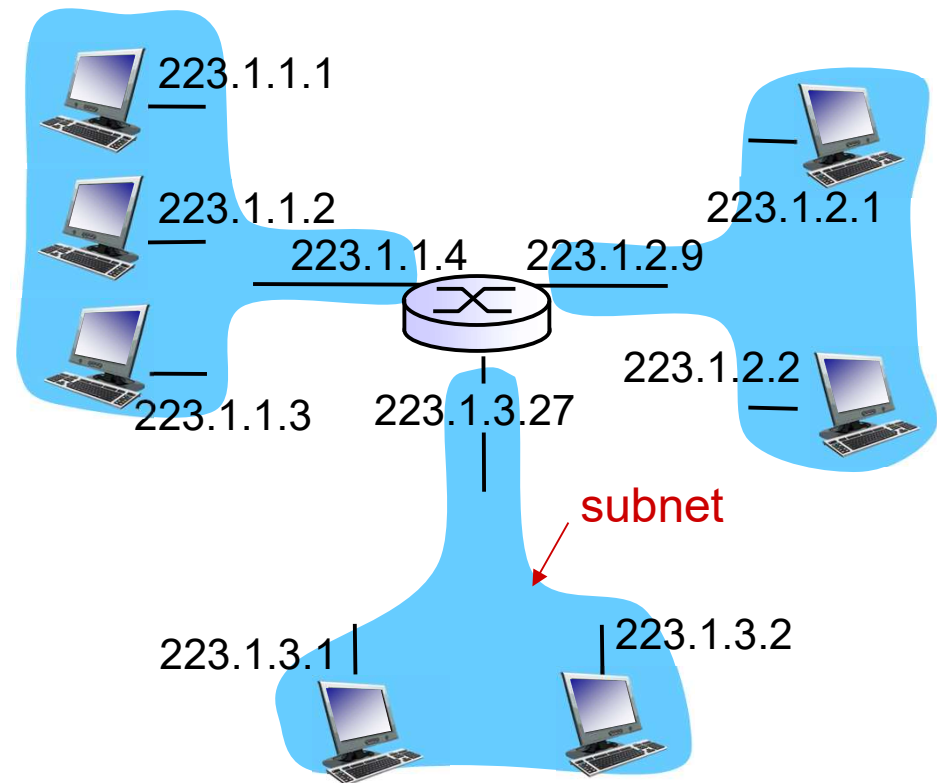
For now: don't need to worry about how one interface is connected to another (with no intervening router)



A: wireless WiFi interfaces connected by WiFi base station

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*

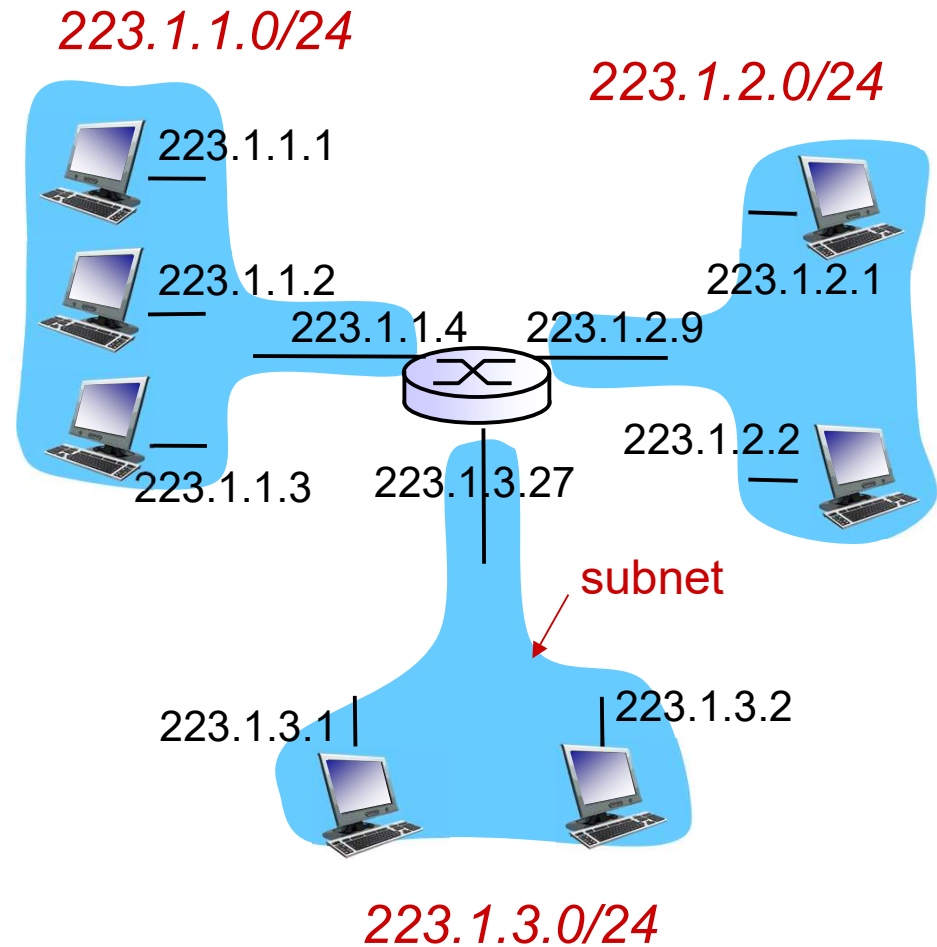


network consisting of 3 subnets

Subnets

recipe

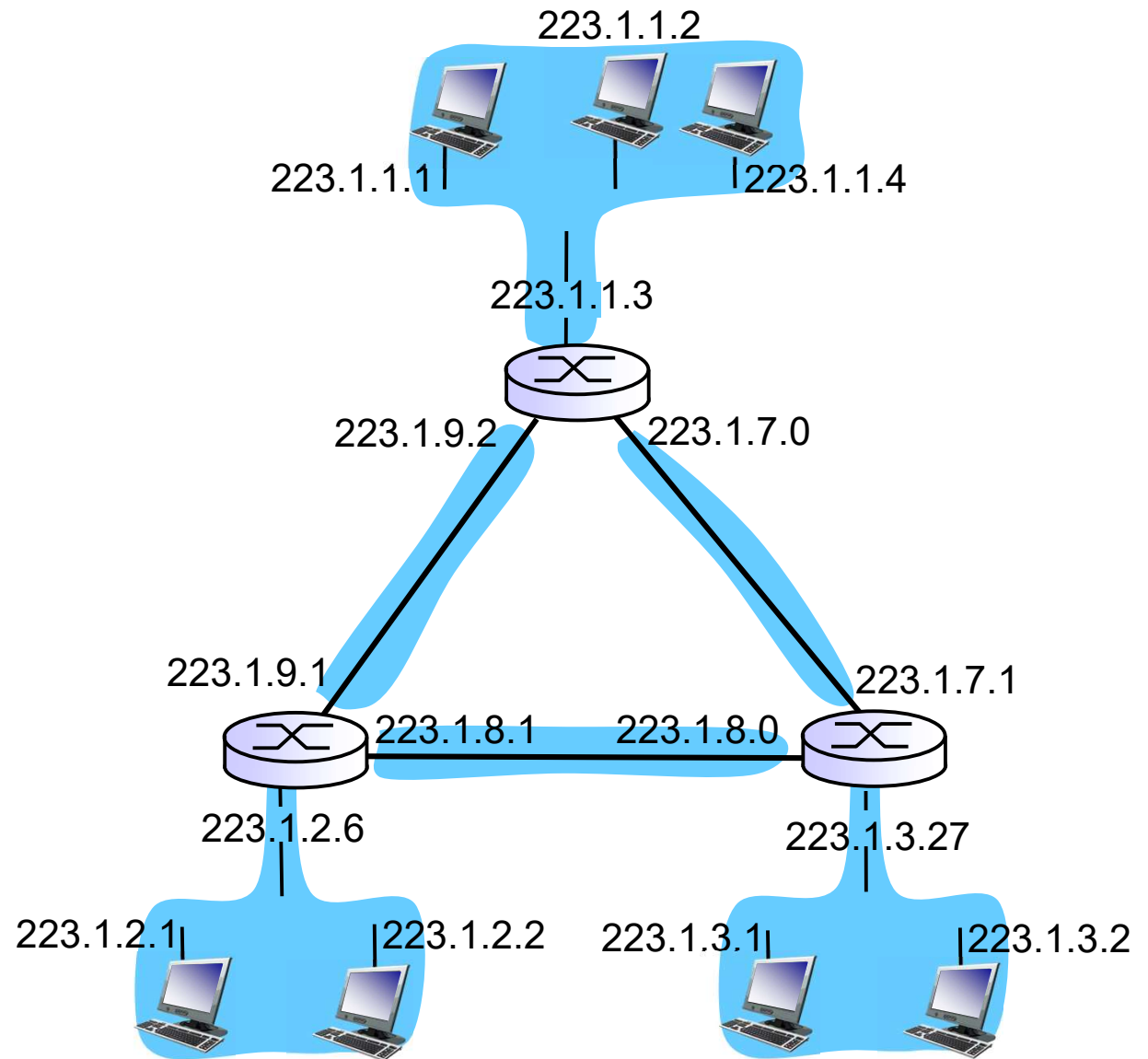
- to determine the subnets, detach each interface from its host or router, creating islands of isolated networks
- each isolated network is called a *subnet*



subnet mask: /24

Subnets

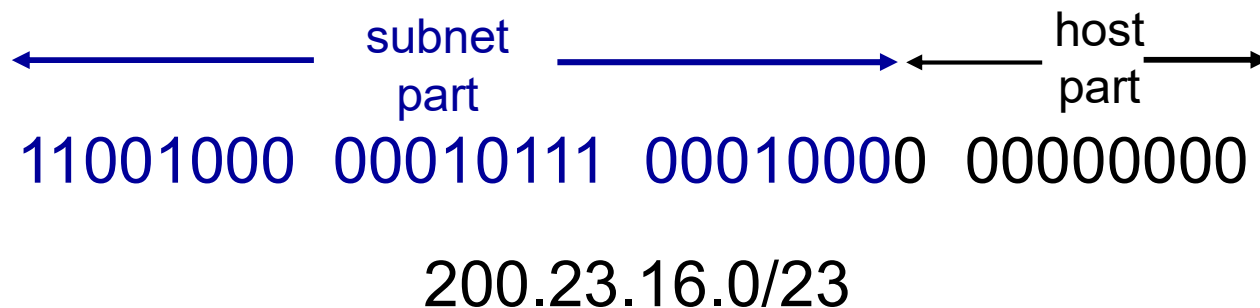
how many?



IP addressing: CIDR

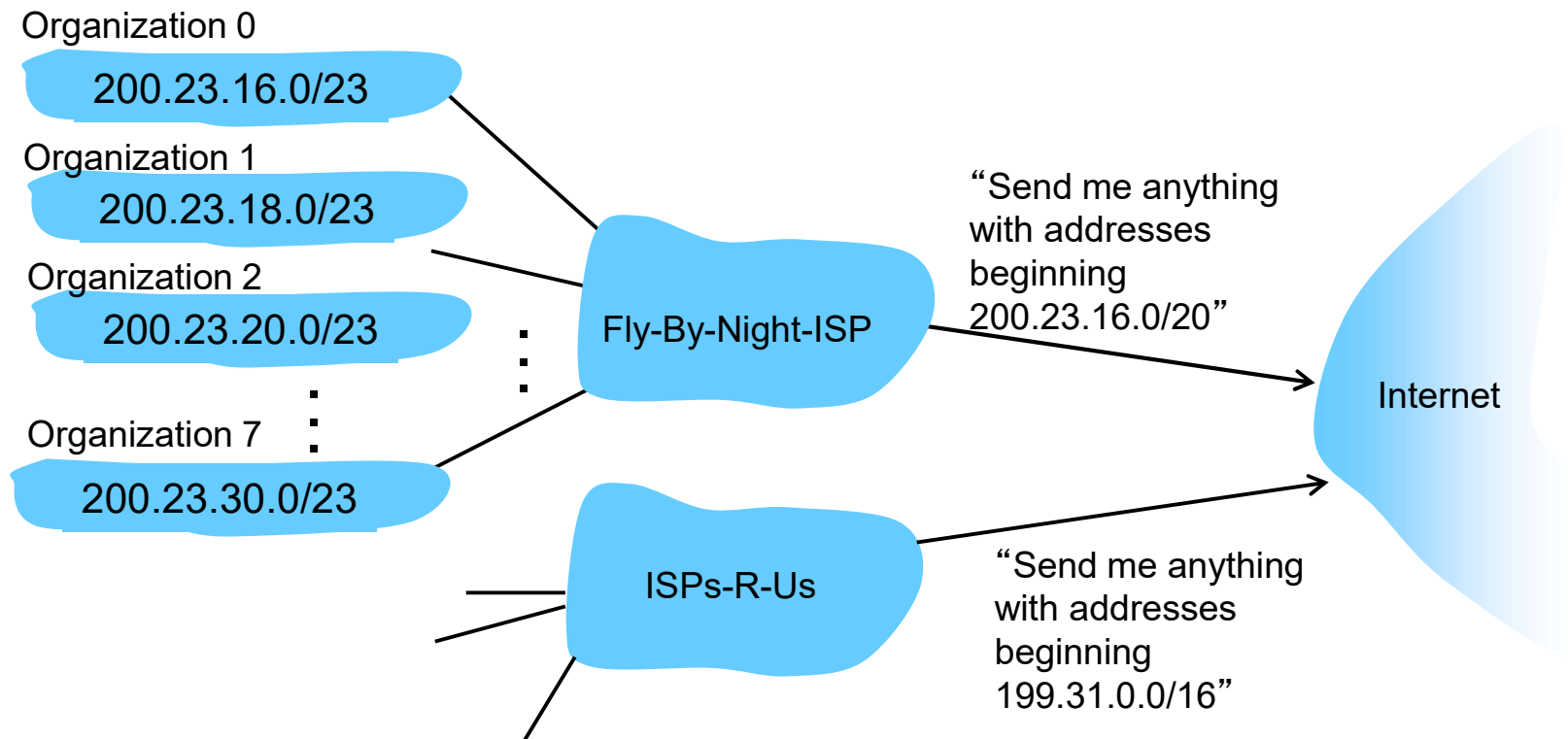
CIDR: Classless InterDomain Routing

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



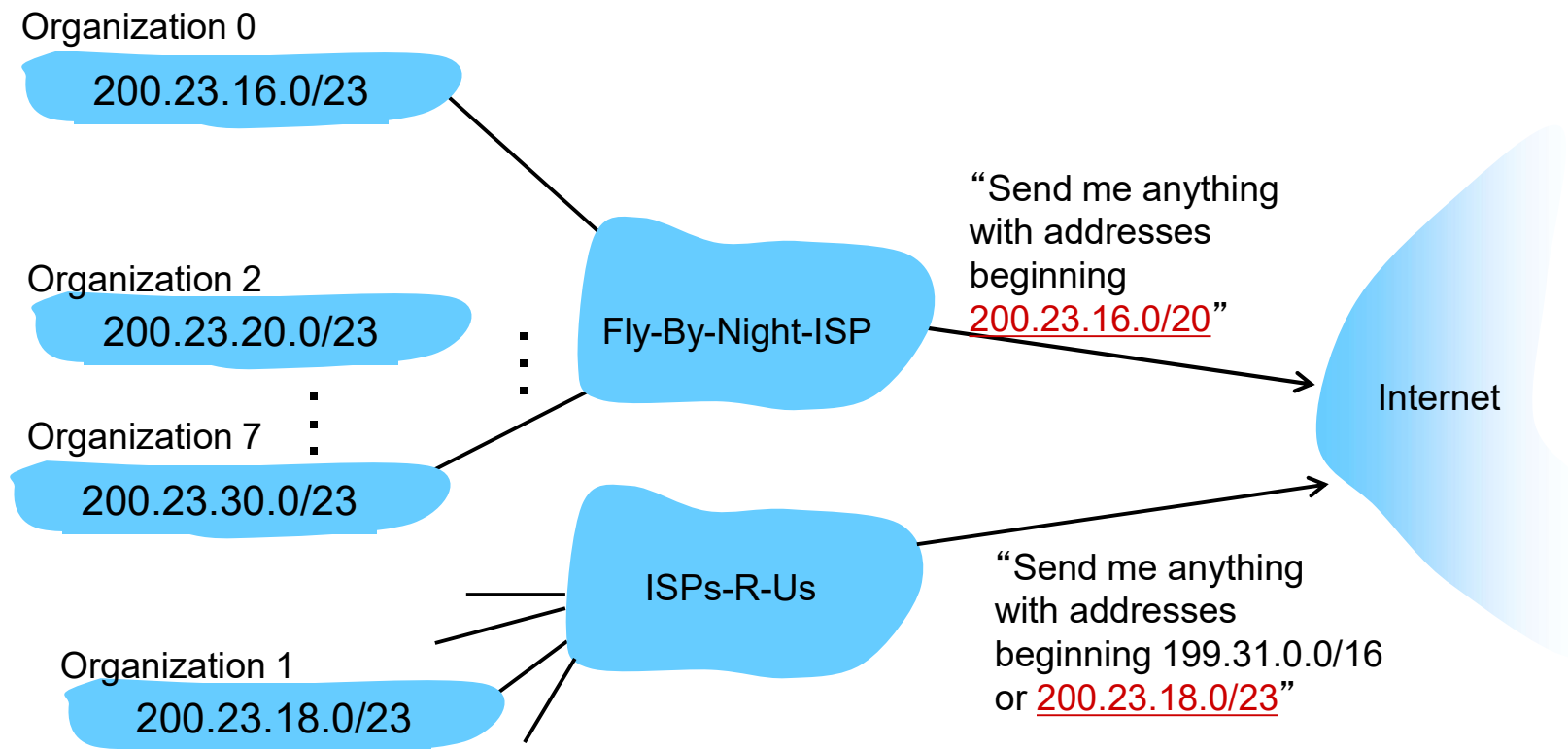
Hierarchical addressing: route aggregation

hierarchical addressing allows efficient advertisement of routing information:



Hierarchical addressing: more specific routes

ISPs-R-U has a more specific route to Organization 1
→ Longest Prefix Matching



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?

DA: 11001000 00010111 00011000 10101010

which interface?

IP addresses: how to get one?

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

- hard-coded by system admin in a file
- **DHCP: Dynamic Host Configuration Protocol:**
dynamically get address from as server
 - “plug-and-play”

DHCP: Dynamic Host Configuration Protocol

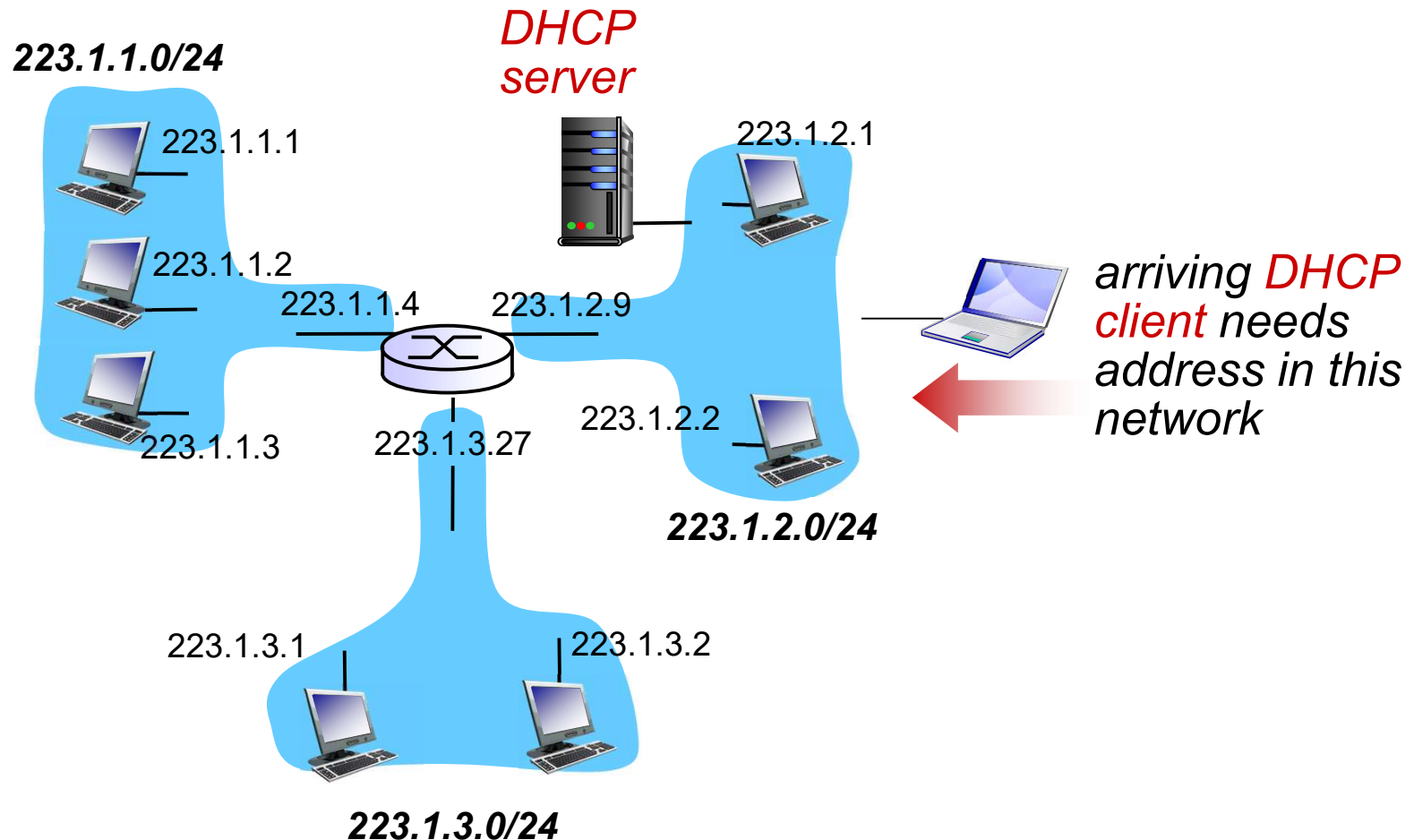
goal: allow host to *dynamically* obtain its IP address from network server when it joins network

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

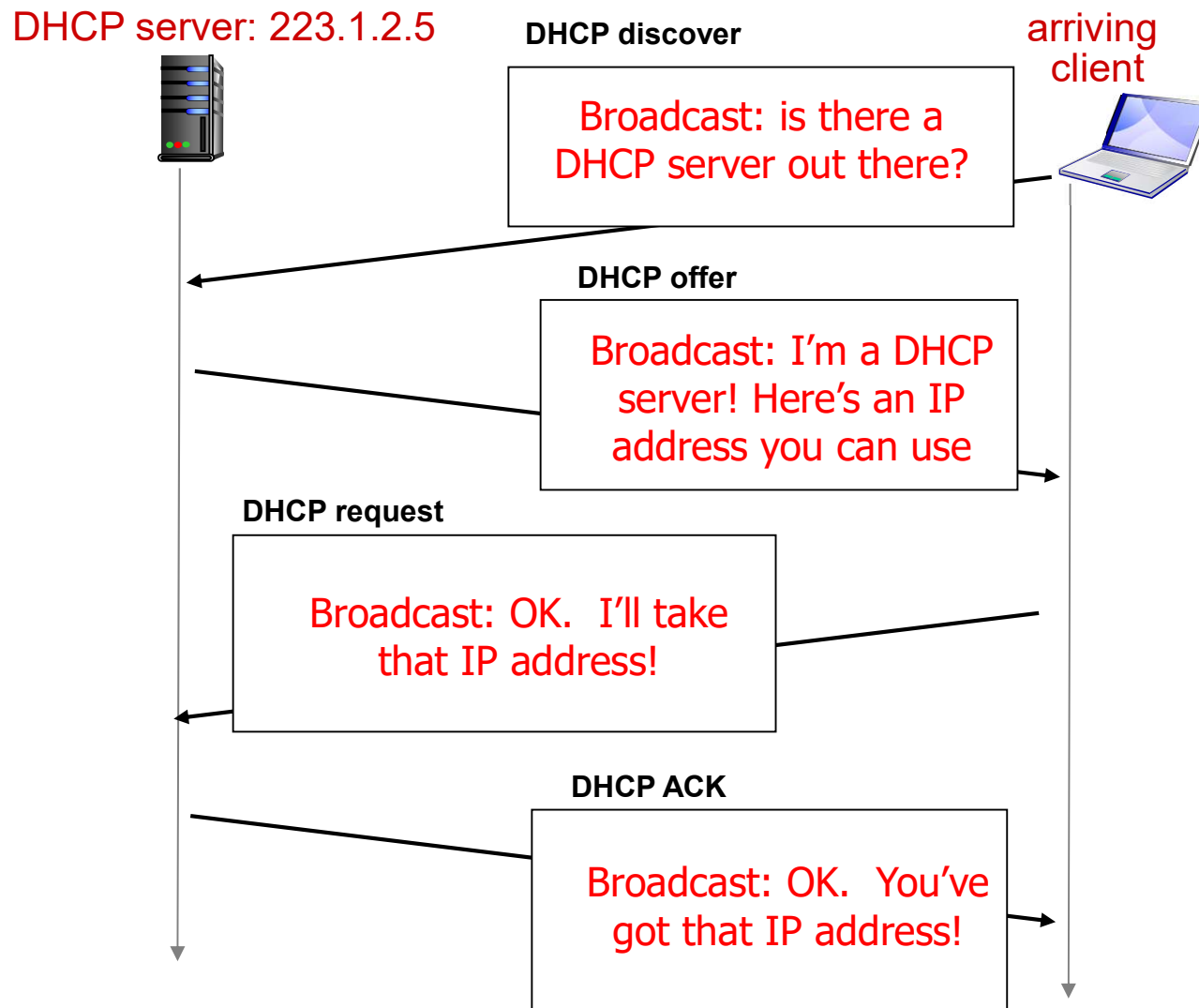
DHCP overview:

- 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



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)

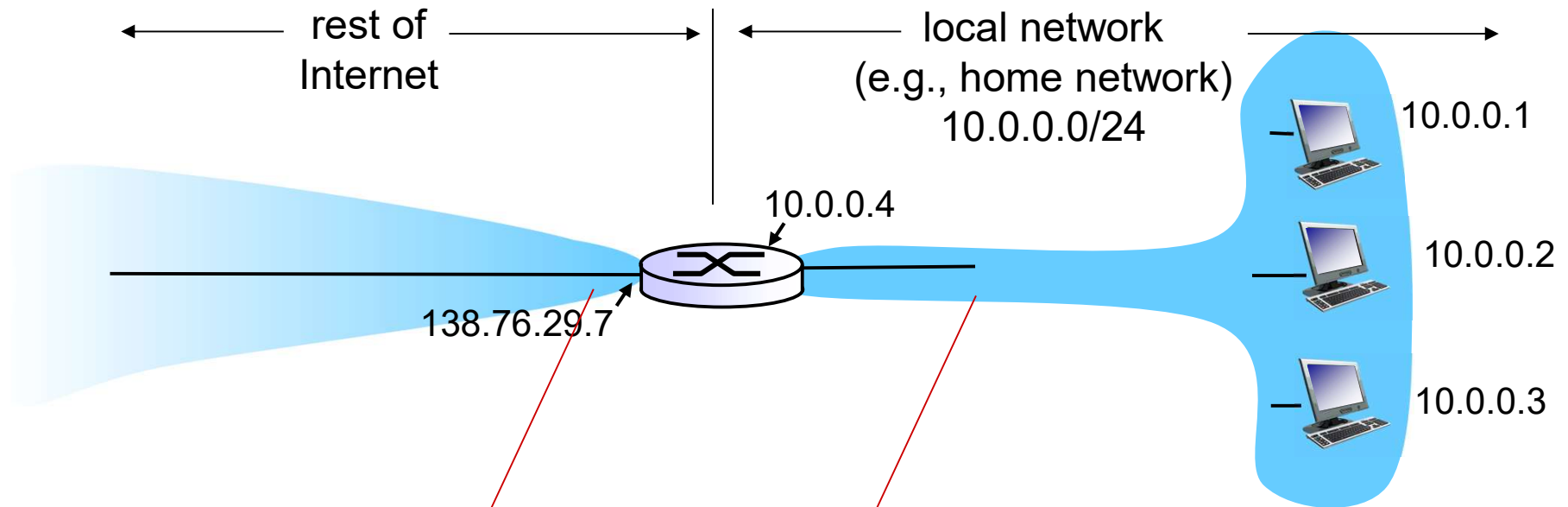
IP addresses: how to get one?

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

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 a 10.0.0.0/24 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:

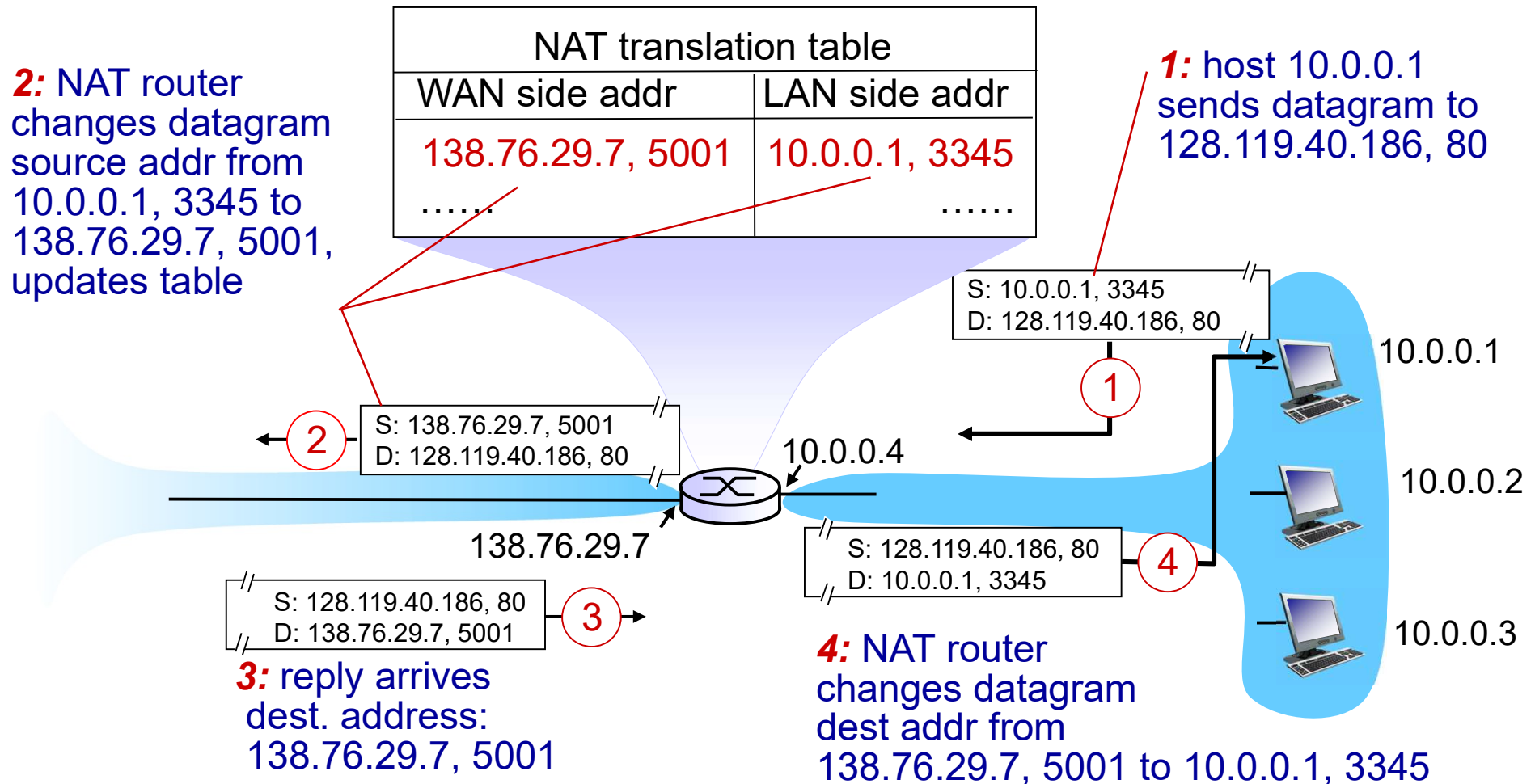
- range of addresses not needed from ISP: just one IP address for all devices
- can change addresses of devices in local network without notifying outside world
- can change ISP without changing addresses of devices in local network
- devices inside local net not explicitly addressable, visible by outside 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



* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive/