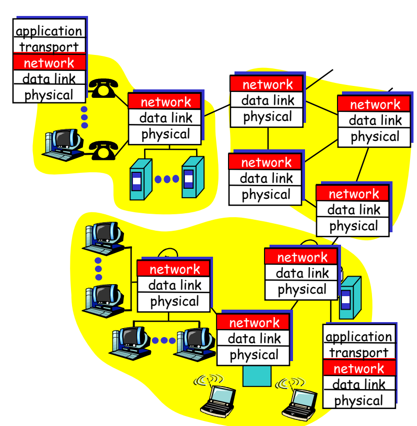
Network layer: Overview

- ❒ Network layer functions
- ❒ IP
- ❒ Routing and forwarding
- ❒ NAT
- ❒ ARP
- ❒ IPv6
- ❒ Routing

Network Layer Functions

- ❒ Transport packet from sending to receiving hosts
- ❒ Network layer protocols in *every* host, router

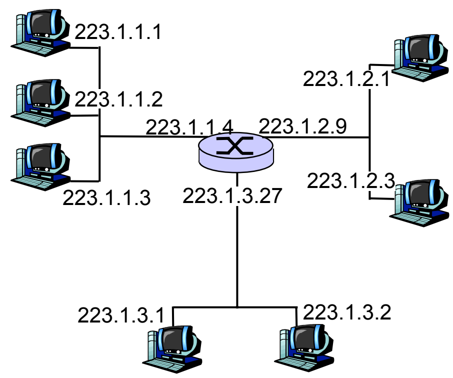


Three important functions:

- ❒ *Path determination:* route taken by packets from source to dest. *Routing algorithms*
- ❒ *Switching:* move packets from router's input to appropriate router output

IP addressing

- IP address: 32-bit identifier for host, router *interface*
- *Interface:* connection between host, router and physical link
  - routers typically have multiple interfaces
  - host may have multiple interfaces
  - IP addresses associated with interface, not host, router



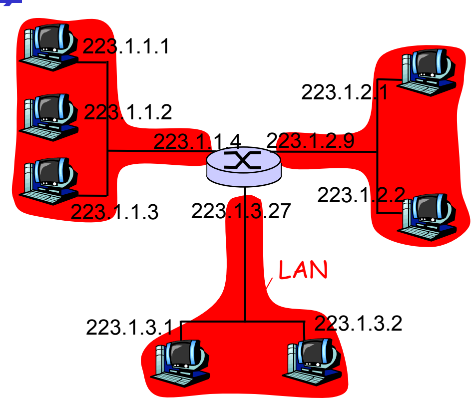
223.1.1.1 = 11011111 00000001 00000001 00000001

223 1 1 1

3

IP addressing (2)

- IP address:
  - Network part (high order bits)
  - Host part (low order bits)
- *What's a network?* (from IP address perspective)
  - Device interfaces with same network part of IP address
  - Can physically reach each other without intervening router



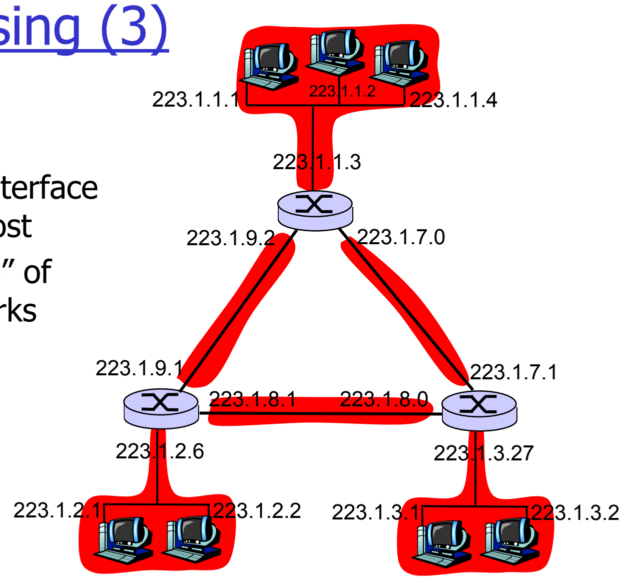
Network consisting of 3 IP networks (for IP addresses starting with 223, first 24 bits are network address)

4

IP addressing (3)

How to find the networks?

- Detach each interface from router, host
- Create "islands" of isolated networks



Interconnected system consisting of six networks

5

IP networks: Subnets

- Sub divide address space
  - network part
  - host address
- Address format: a.b.c.d/x, where x is # bits in subnet portion of address

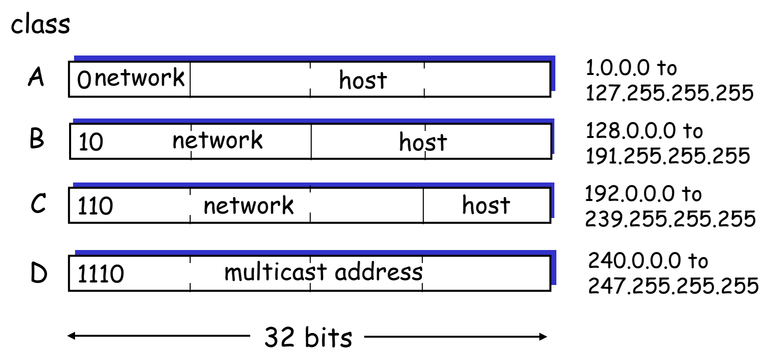
← subnet part → ← host part →

11001000 00010111 00010000 00000000

200.23.16.0/24

6

Fixed subnetting (classful)



7

Address management

- Problem: We are running out of networks
- Solution (a):
  Subnetting: e.g., Class B Host field (16 bits) is subdivided into <subnet;host> fields
- Solution (b):
  CIDR (Classless Inter Domain Routing)

8

CIDR

CIDR: Classless InterDomain Routing

- Motivation
  - Class A is too large, Class C is too small
  - Everyone had a Class B address!!!

- Solution:
  - Sites are given contiguous blocks of class-C addresses (256 addresses each) and a mask or parts of former class A/B networks.

9

CIDR (2.)

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

← subnet part → ← host part →

11001000 00010111 00010000 00000000

200.23.16.0/23

10

IP addresses: How to get one?

Q: How does *host* get IP address?

- Hard-coded by system admin in a file
  - Wintel: Control Panel → Network → Configuration → TCP/IP → Properties
  - UNIX: /etc/rc.config
- DHCP: Dynamic Host Configuration Protocol: dynamically get address from as server
  - "Plug-and-play"
- IP / Subnets allocated by provider (RIPE/ARIN/…)

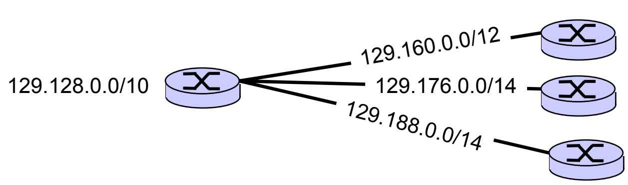
Hierarchical address structure

- Recall: CIDR

18 relevant bits

128.119.48.12/18 = 10000000 01110111 00110000 00001100

  - High order bits form the **prefix**
  - Once inside the network, can **subnet**: divide remaining bits
  - Subnet example:



Note: picture shows prefix masks, not interface addrs!

- **Forwarding decision: Longest prefix match**

Forwarding vs. routing

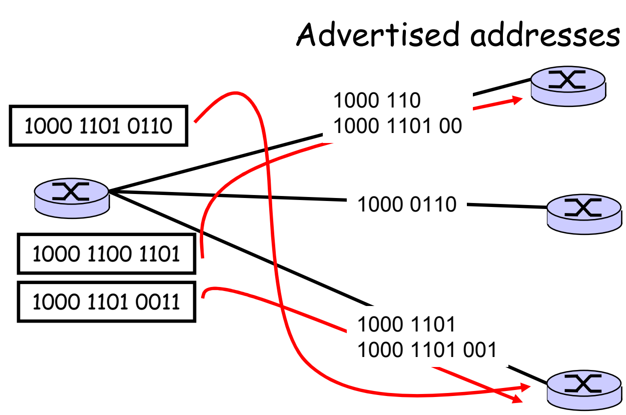
- **Forwarding:** the process of moving packets from input to output
  - The forwarding table
  - Information in the packet
- **Routing:** process by which the forwarding table is built and maintained
  - One or more routing protocols
  - Procedures (algorithms) to convert routing info to forwarding table.

(More later …)

13

Forwarding with CIDR

- Packet should be sent toward the interface with the **longest matching prefix**



14

CIDR (3.)

- Repeated "aggregation" within same provider leads to shorter and shorter prefixes
- CIDR helps also routing table size and processing: Gateways keep only prefixes and find "longest prefix" match
- Class-C networks are also partitioned by geography e.g., Europe got 194.0.0.0 to 195.255.255.255

15

Lookup: Longest prefix match

- Forwarding table:
  <Network>/<mask> <next-hop>
- IP Packets: destination IP address
  - Find next-hop via longest prefix match
- Example:

Forwarding table		Packets
134.96.252.0/24	A	134.96.252.200
134.96.0.0/16	C	134.96.254.2
134.96.240.0/20	B	134.96.239.200
134.96.252.192/28	B	134.97.239.200
134.96.252.128/28	A	134.96.252.191

16

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

Q: What do I do if I don't have a public address?

A: Private IP addresses (RFC 1918)

- 10/8
- 172.16/12
- 192.168/16

- Private use only – not routable in the Internet

17

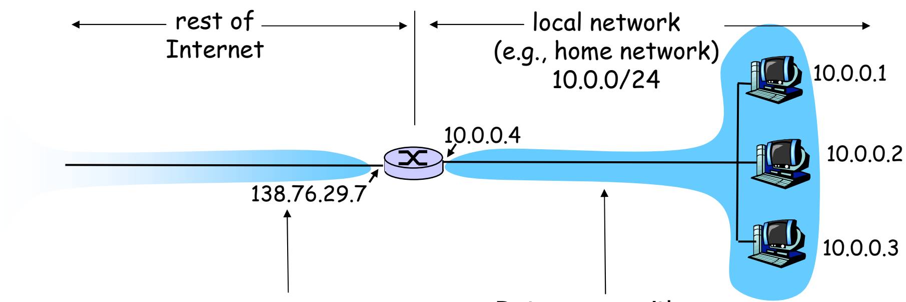
NAT: Network address translation

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

- Just one IP address for all devices
- Not needed range of addresses from ISP

18

NAT: Network address translation (2.)



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)

19

NAT: Network address translation (3.)

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).

20

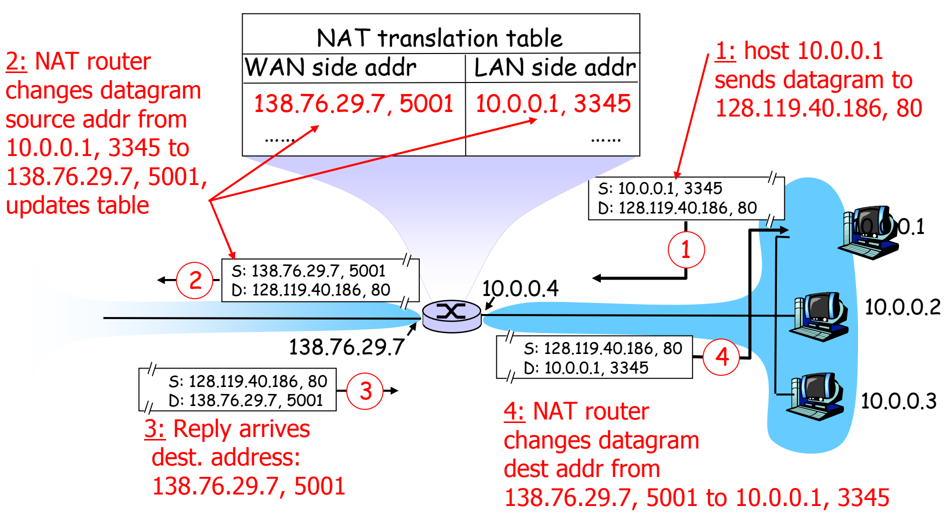
NAT: Network address translation (4.)

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

21

NAT: Network address translation (5.)



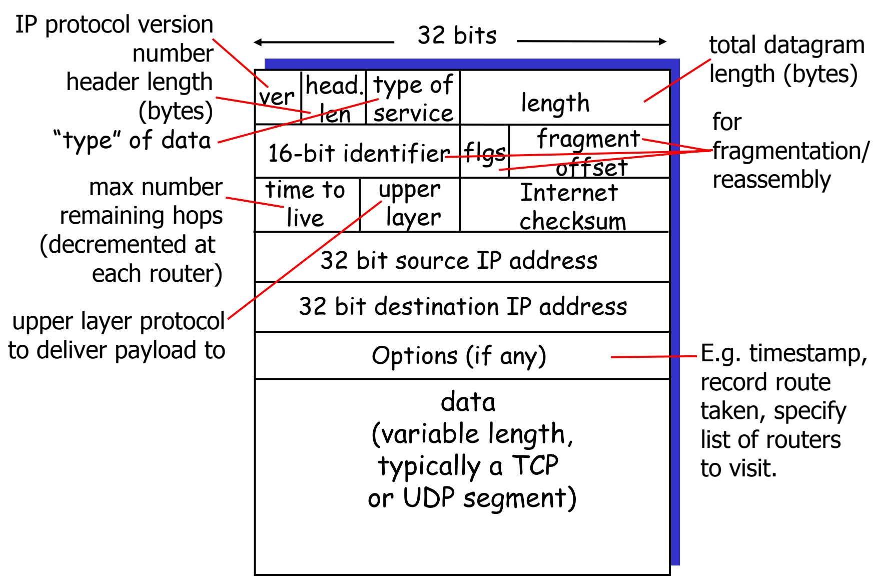
22

NAT: Network address translation (6.)

- 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, e.g., P2P applications
  - Address shortage should instead be solved by IPv6

23

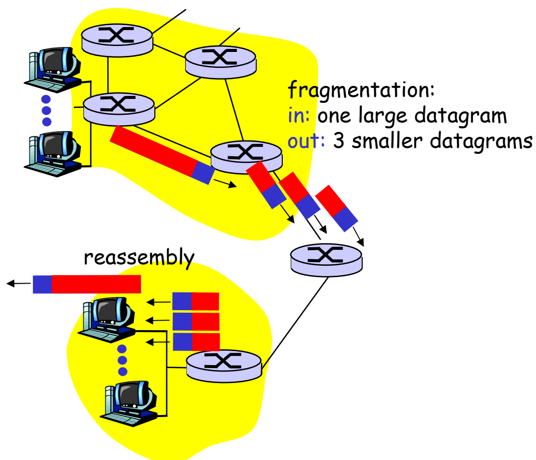
IPv4 Datagram Format



24

IP fragmentation and reassembly

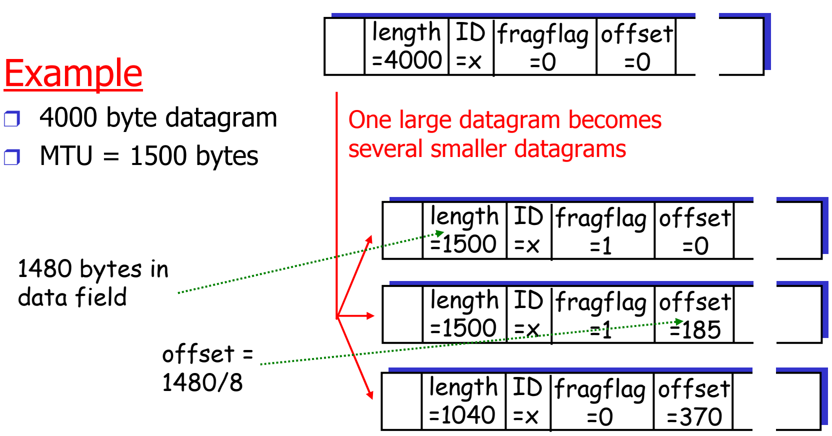
- Network links have MTU (max. transfer size) – largest possible link-level frame.
  - Different link types, different MTUs
- Large IP datagram divided ("fragmented") within net
  - One datagram becomes several datagrams
  - "Reassembled" only at final destination
  - IP header bits used to identify, order related fragments



IP fragmentation and reassembly (2.)

Example

- 4000 byte datagram
- MTU = 1500 bytes



ICMP: Internet control message protocol

- Used by hosts, routers, gateways to communication 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

27

Address resolution protocol (ARP)

- Interface between Link layer and Network Layer
- Allows hosts to query who owns an IP address on the same LAN
- Owner responds with hardware address
- Allows changes to link layer to be independent of IP addressing

28

Network layer: Status

- Network layer functions
- IP
- Routing and forwarding
- NAT
- ARP
- IPv6
- Routing

29