CSCI 4760 - Computer Networks
Fall 2016

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These slides are adapted from the textbook slides by J.F. Kurose and K.W. Ross

Chapter 4: Network Layer

Chapter goals:

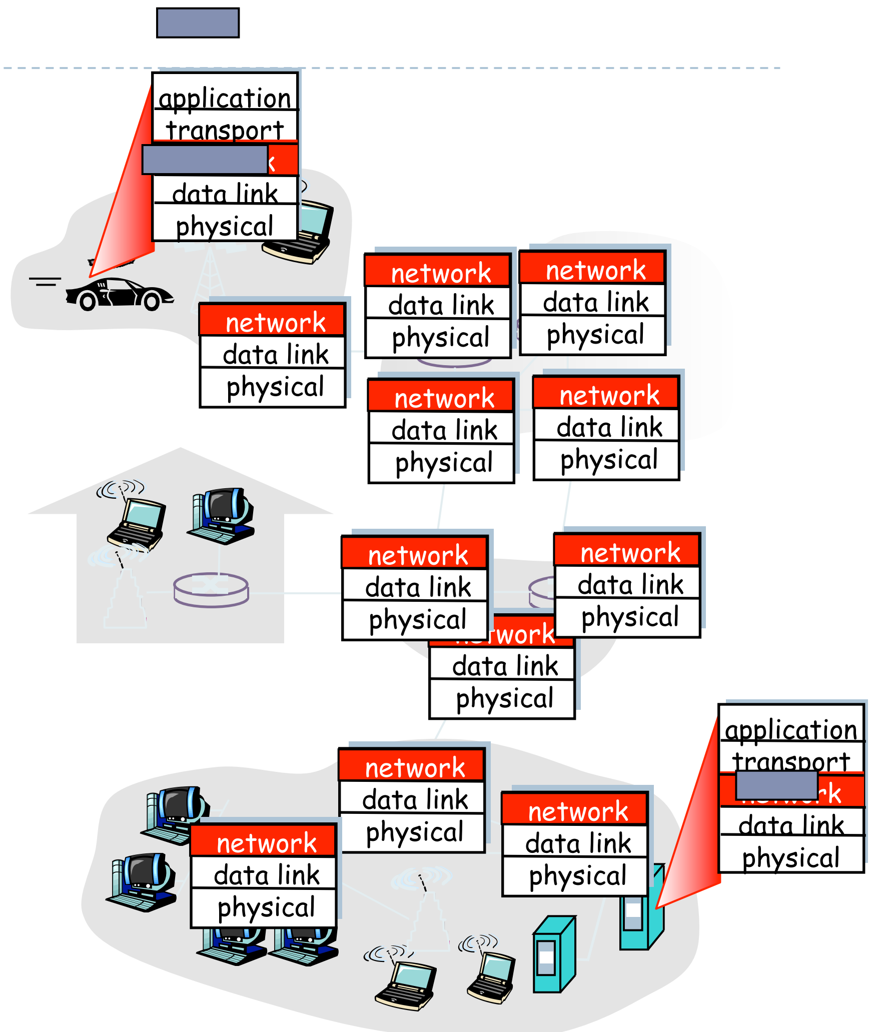
- understand principles behind network layer services:
  - network layer service models
  - forwarding versus routing
  - how a router works
  - routing (path selection)
  - dealing with scale
  - advanced topics: IPv6, mobility
- instantiation, implementation in the Internet

Chapter 4: Network Layer

- 4.1 Introduction
- 4.2 Virtual circuit and datagram networks
- 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

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



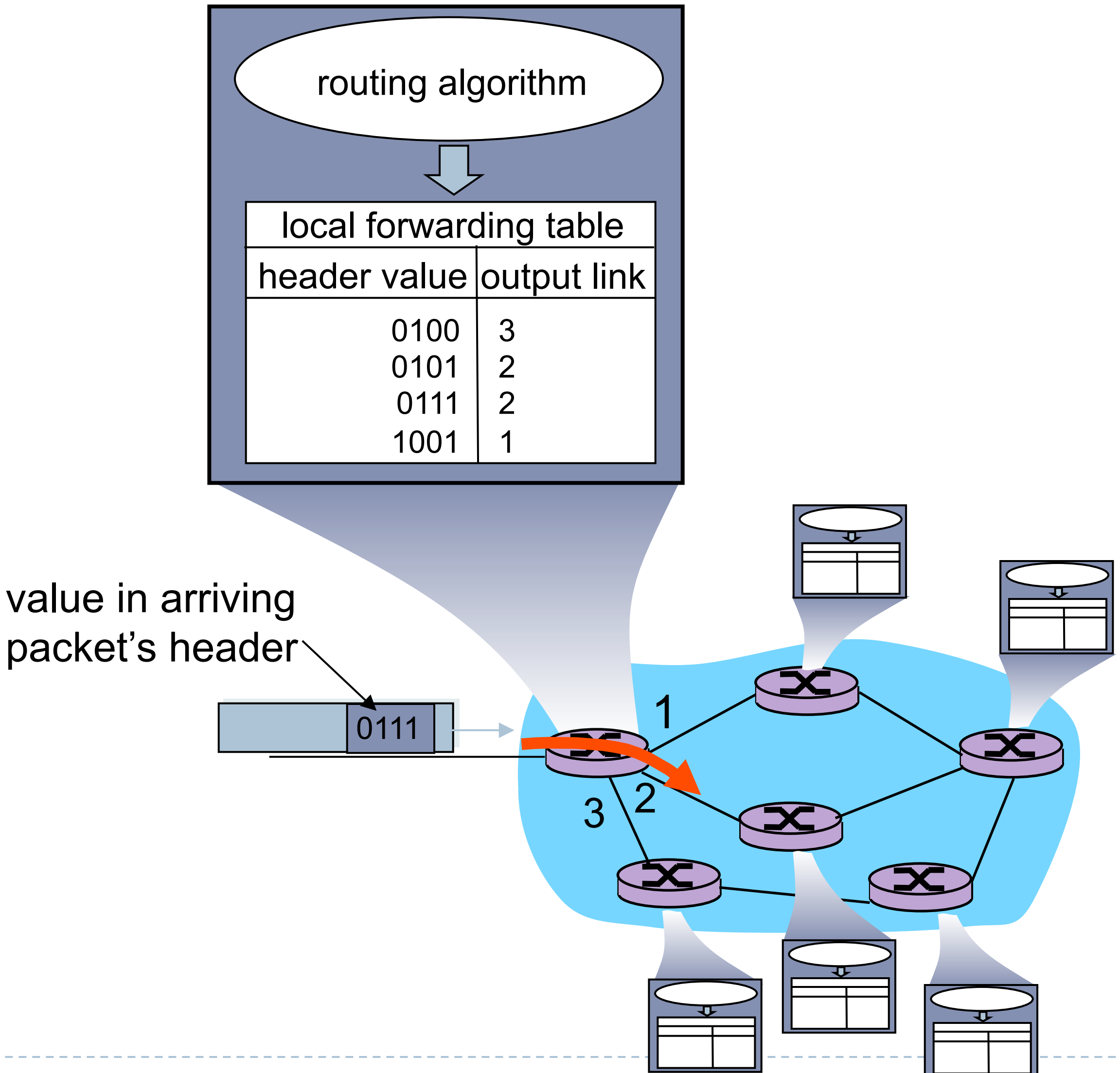
Two Key Network-Layer Functions

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

analogy:

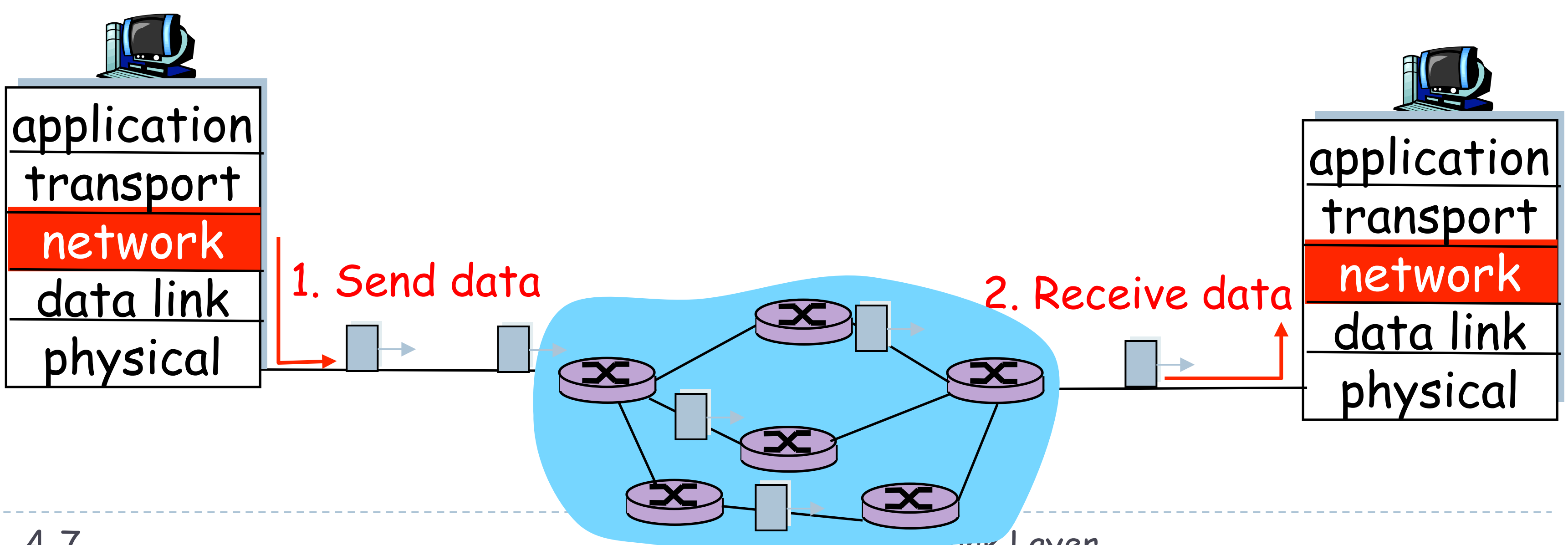
- routing: process of planning trip from source to dest
- forwarding: process of getting through single interchange

Interplay between routing and forwarding



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



IPv4 forwarding table

2^32 = 4 billion possible entries

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

Longest prefix matching

Prefix Match	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?

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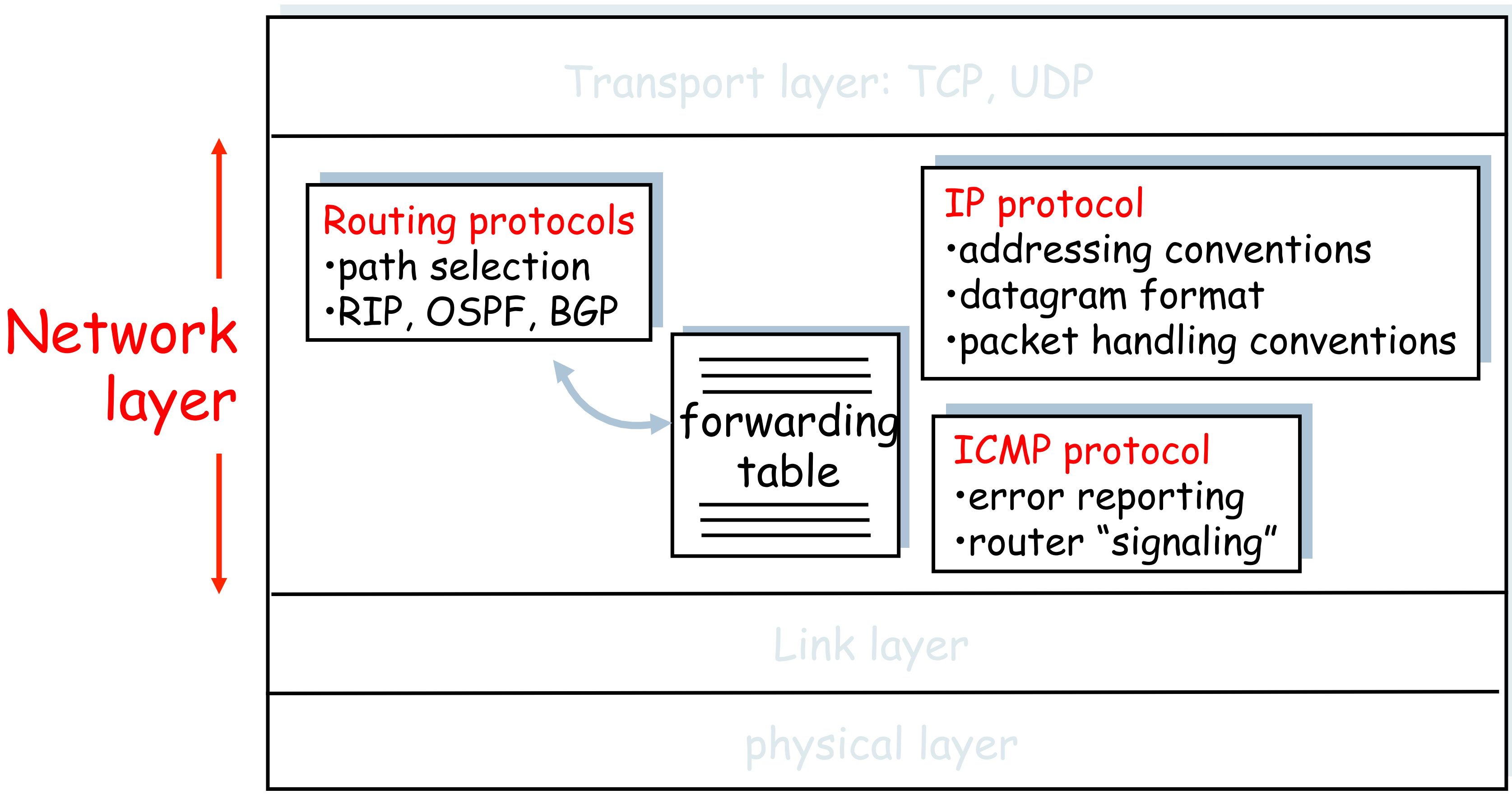
The Internet Network layer

Host, router network layer functions:



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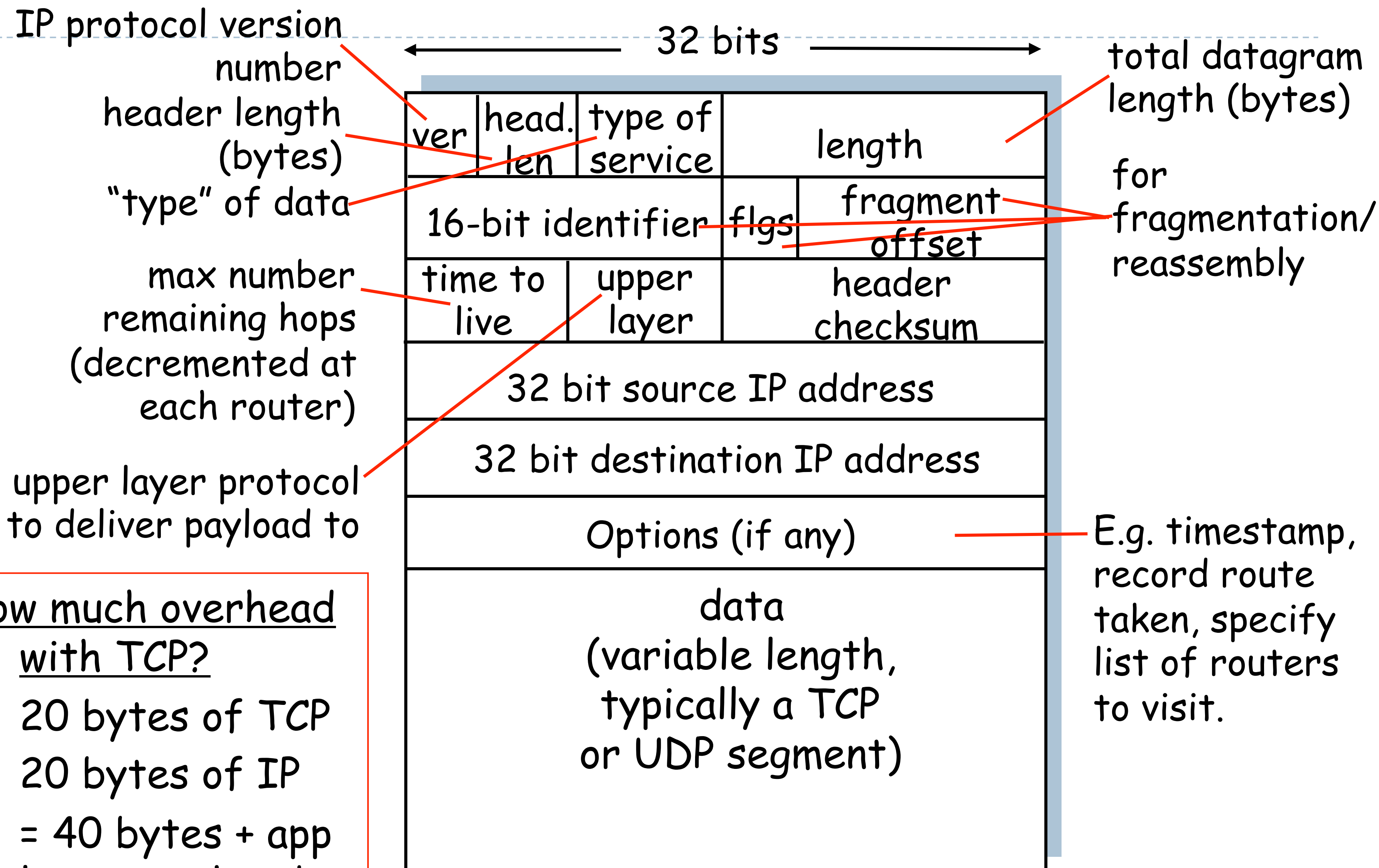
IPv4 datagram format

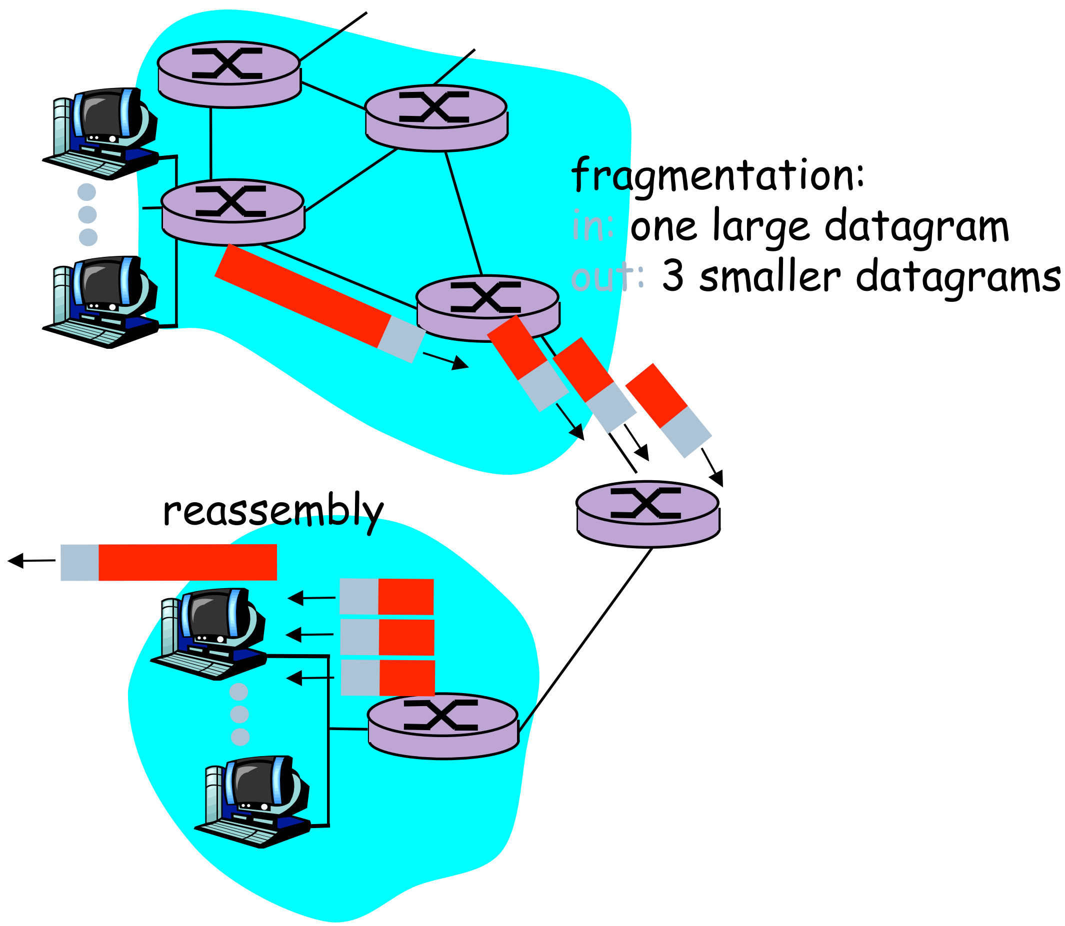


how much overhead with TCP?

- 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



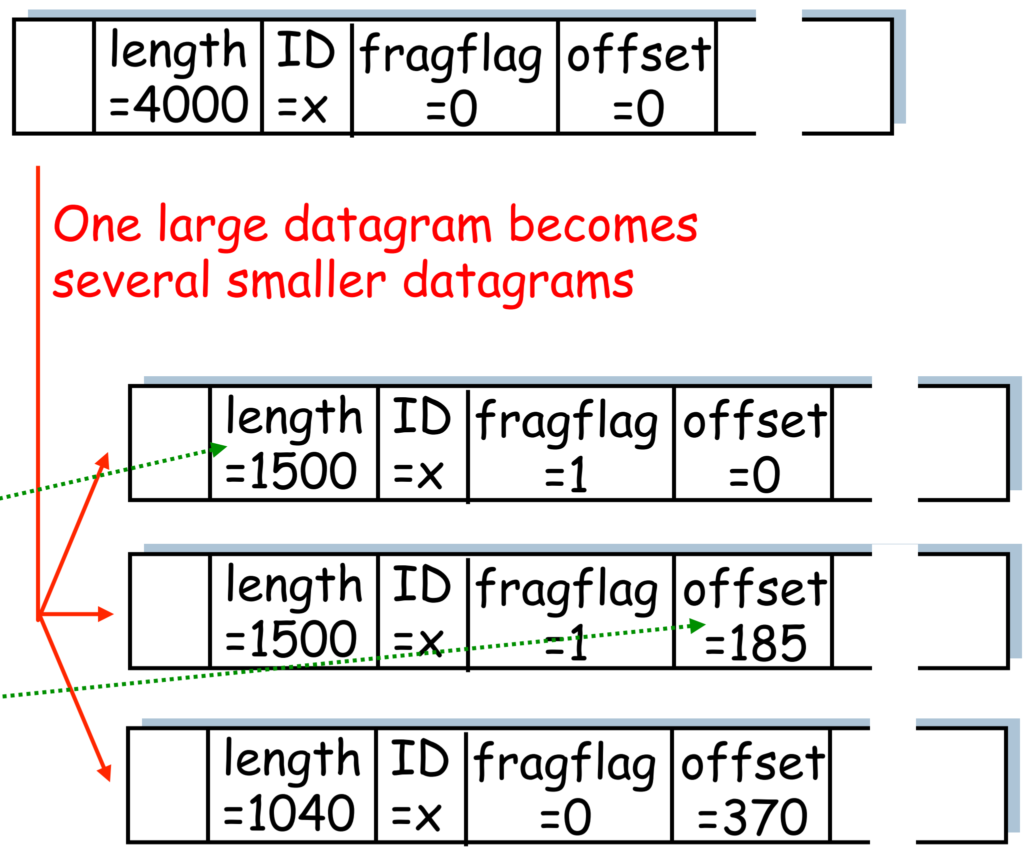
IP Fragmentation and Reassembly

Example

- 4000 byte datagram (3980 Bytes for payload)
- MTU = 1500 bytes

1480 bytes in data field

offset = 1480/8 = 185



IP Fragmentation - Another Example

- Initial MTU = 3100 bytes (=3080 payload bytes)
- As packet is routed, it encounters a link with MTU = 820 bytes (=800 payload bytes)
- How will the fragments look like?
  - ID = 4325, Flag = 1, offset = 0, length = 820
  - ID = 4325, Flag = 1, offset = 100, length = 820
  - ID = 4325, Flag = 1, offset = 200, length = 820
  - ID = 4325, Flag = 0, offset = 300, length = 700

IP Fragmentation - Another Example

- Initial MTU = 3100 bytes (=3080 payload bytes)
- As packet is routed, it encounters a link with MTU = 930 bytes (=910 payload bytes)
- How will the fragments look like?
  - ID = 4325, Flag = 1, offset = 0, length = 924
  - ID = 4325, Flag = 1, offset = 113, length = 924
  - ID = 4325, Flag = 1, offset = 226, length = 924
  - ID = 4325, Flag = 0, offset = 339, length = 388

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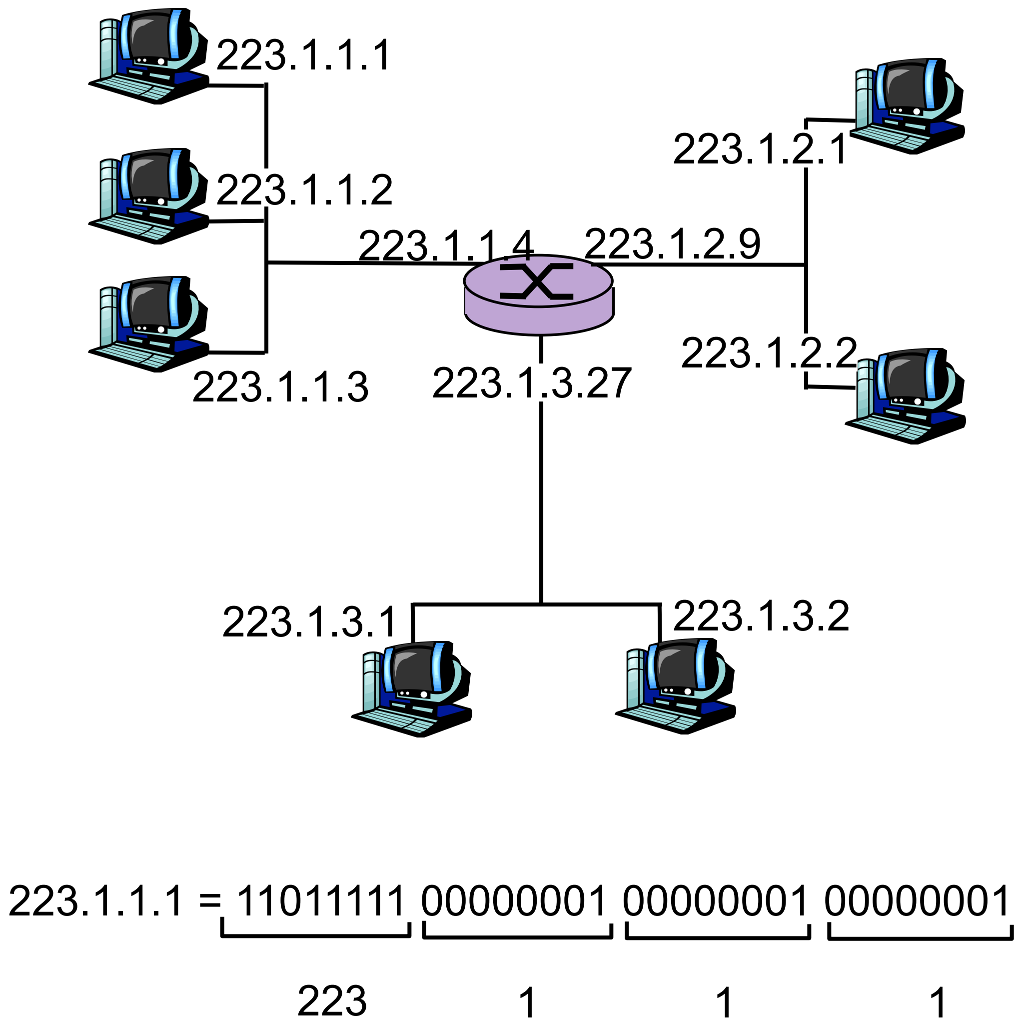
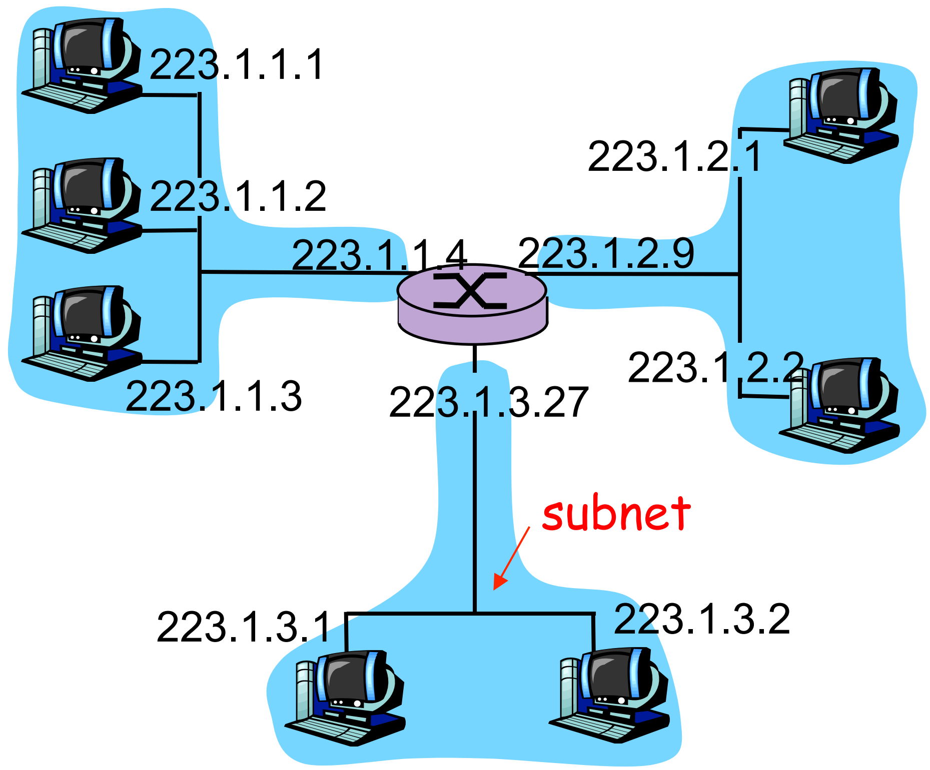
IPv4 Addressing: introduction

- IPv4 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



Subnets

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

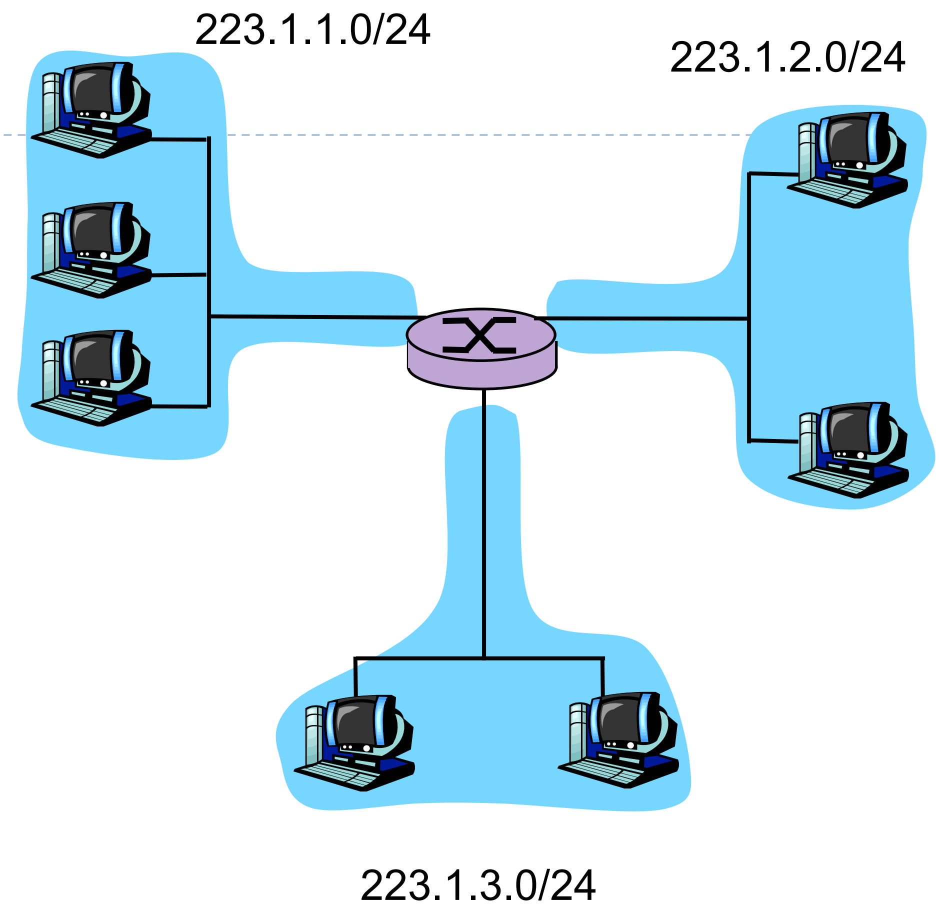


network consisting of 3 subnets

Subnets

Recipe

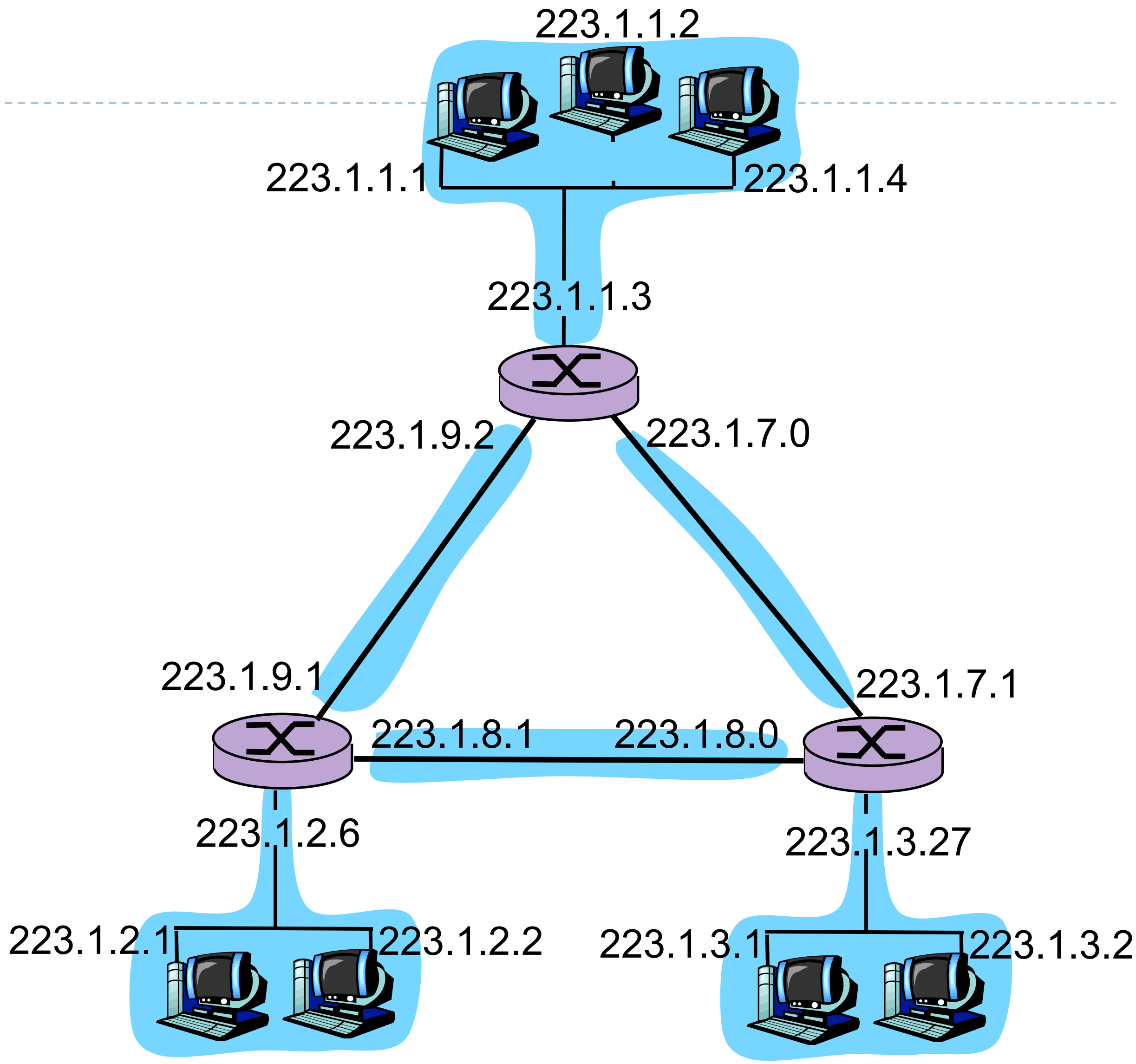
- To determine the subnets, detach each interface from its host or router, creating islands of isolated networks. Each isolated network is called a subnet.



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

subnet part | host part

11001000 00010111 00010000 00000000

200.23.16.0/23

Computing the longest common CIDR

- 192.168.6.98
  - 192.168.(00000110).(01100010)
- 192.168.65.3
  - 192.168.(01000001).(00000011)
- CIDR
  - 192.168.(00000000).(00000000)/17
  - 192.168.0.0/17
- Subnet Mask
  - 255.255.(10000000). (00000000)
  - 255.255.128.0
  - IP & SM = CIDR

- 172.18.5.215
  - 172.18.5.(11010111)
- 172.18.5.210
  - 172.18.5.(11010010)
- CIDR
  - 172.18.5.(11010000)/29
  - 172.18.5.208/29
- Subnet Mask
  - 255.255.255. (11111000)
  - 255.255.255.248
  - IP & SM = CIDR

Computing the CIDR

- Assume we have the following IP addresses, what is their longest common CIDR?
  - 10.35.25.102, 10.35.27.23, 10.35.28.203, 10.35.30.124
  - CIDR = 10.35.24.0/21
  - Subnet Mask = 255.255.248.0

- Assume we have the following IP addresses, what is their longest common CIDR?
  - 172.17.2.102, 172.17.2.65, 172.17.2.87, 172.17.2.124
  - CIDR = 172.17.2.64/26
  - Subnet Mask = 255.255.255.192

Reserved Address Blocks

- **10.0.0.0/8** **Private network** RFC 1918
- **127.0.0.0/8** **Loopback** RFC 5735
- 169.254.0.0/16 Link-Local RFC 3927
- **172.16.0.0/12** **Private network** RFC 1918
- 192.0.0.0/24 Reserved (IANA) RFC 5735
- 192.0.2.0/24 TEST-NET-1, Documentation and example code RFC 5735
- 192.88.99.0/24 IPv6 to IPv4 relay RFC 3068
- **192.168.0.0/16** **Private network** RFC 1918
- 198.18.0.0/15 Network benchmark tests RFC 2544
- 198.51.100.0/24 TEST-NET-2, Documentation and examples RFC 5737
- 203.0.113.0/24 TEST-NET-3, Documentation and examples RFC 5737
- 224.0.0.0/4 Multicasts (former Class D network) RFC 3171
- 240.0.0.0/4 Reserved (former Class E network) RFC 1700
- **255.255.255.255** **Broadcast** RFC 919