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Computer Networks

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Material with thanks to James F. Kurose, Mosharaf Chowdhury, and other colleagues.

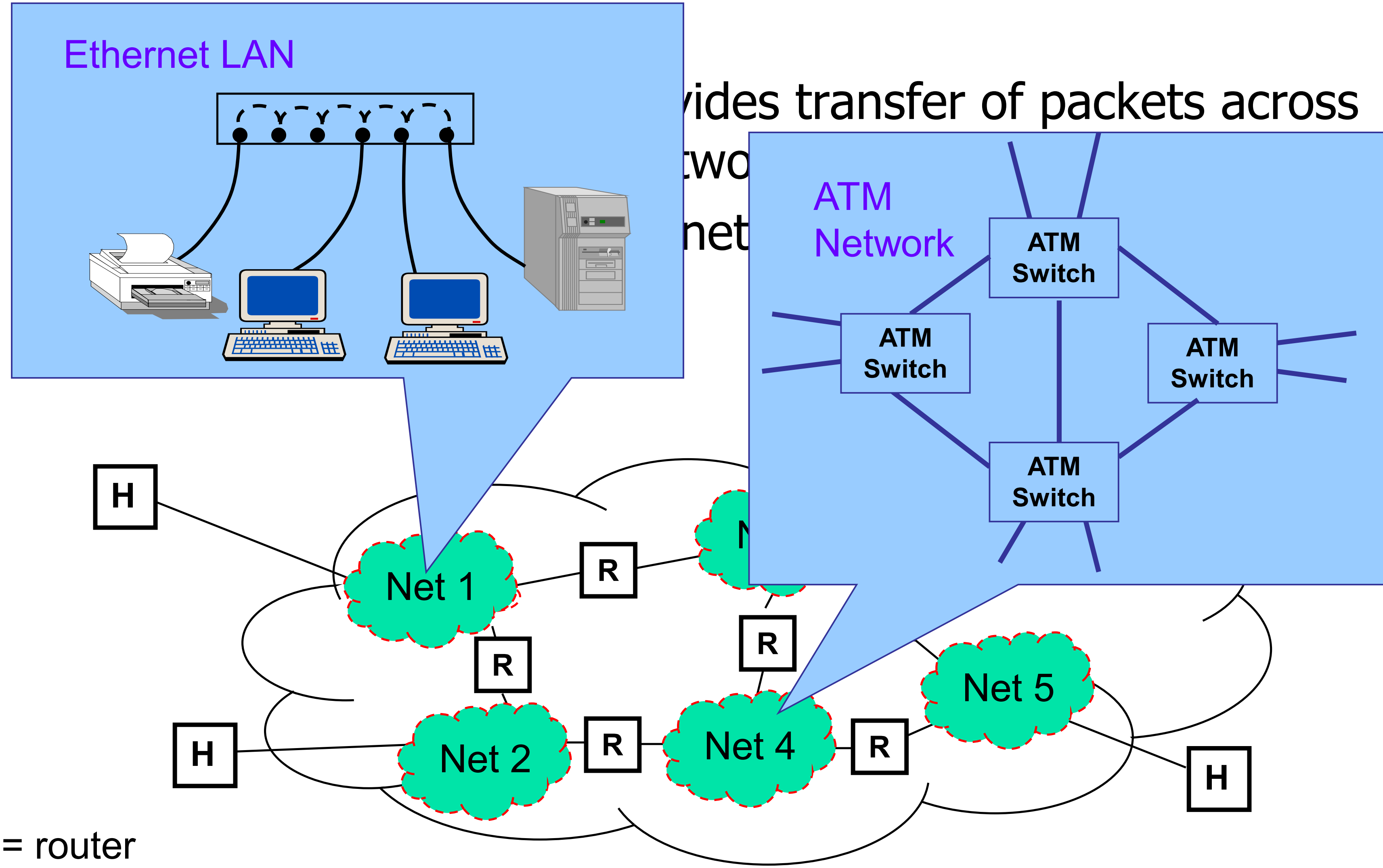
Chapter 3. Network Layer

- Network Layer Functions
- IP Protocol Basic
- IP Protocol Suit
- Routing Fundamentals
- Internet Routing Protocols
- IP Multicasting

- The Internet Protocol
- IP Operations
- IP Packet Structure
- IP Fragmentation
- IP Address

Internetworking

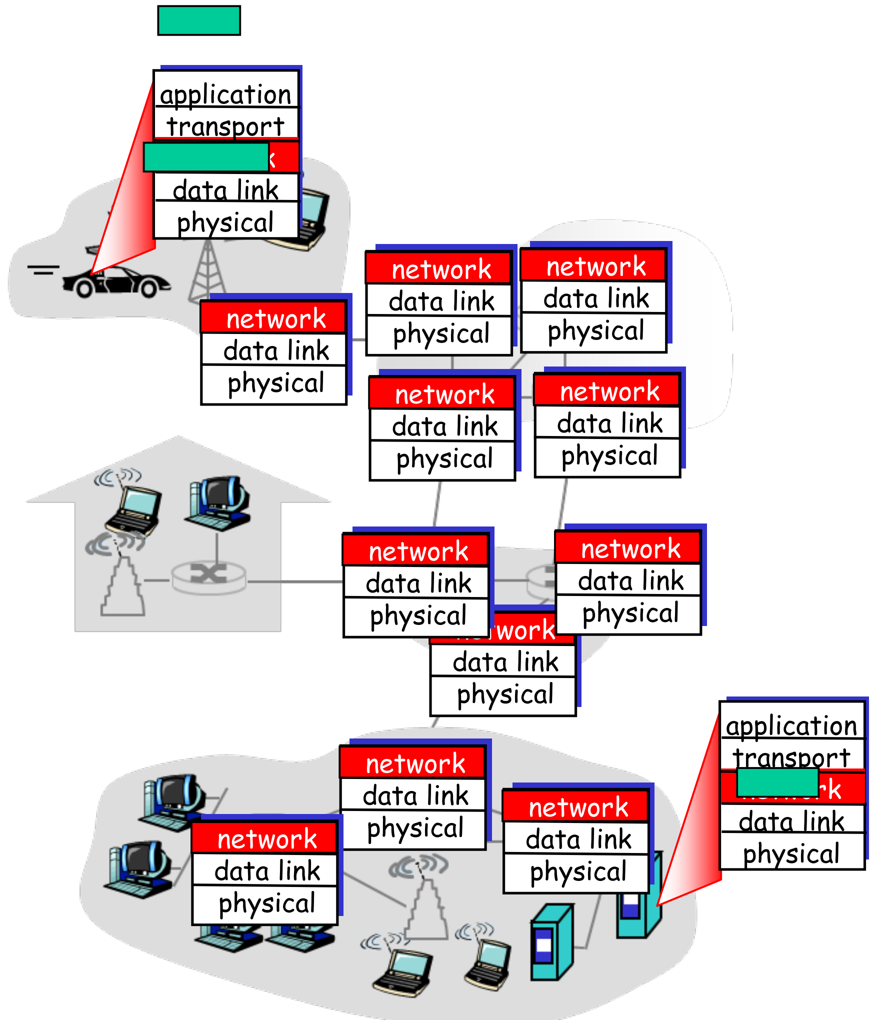
- …vides transfer of packets across …two…
- …net…



R = router
H = host

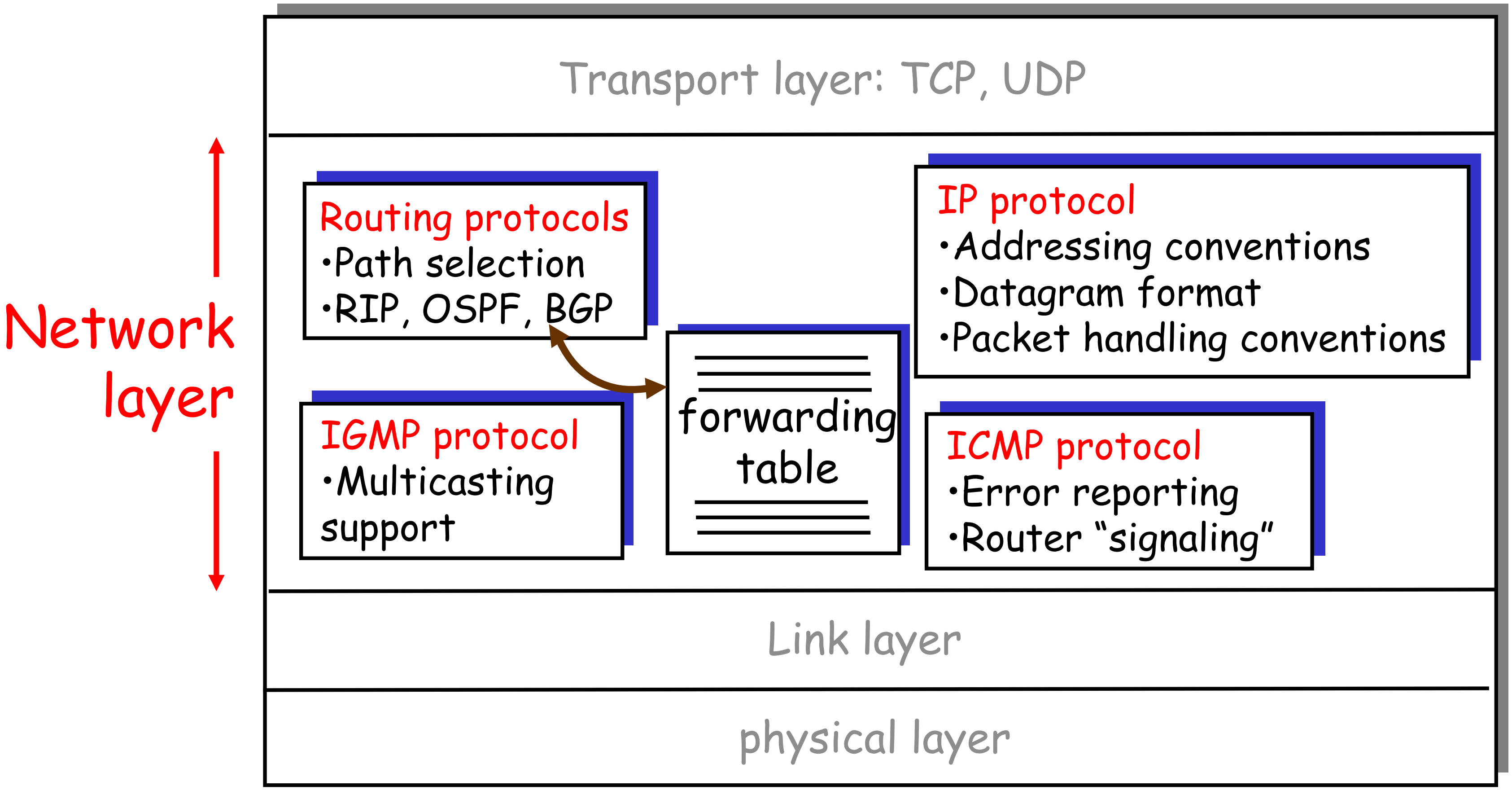
Positions of the IP Protocol

- IP – Internet Protocol
  - Most famous internet protocol developed for ARPANET
  - RFC 791, Internet STD number 5
- IP layer entity resides on each host and router
- Provides connectionless service (i.e. datagram mechanism)



The Internet Network layer

- Host, router network layer functions



Internet Addressing

- Addressing level
- Addressing scope
- Addressing mode

Addressing Level

- Physical network address
  - Used to route PDU within single physical network
- Inter-network address
  - IP address or internet address, used to route PDU across networks
  - Unique address for each end system (host) and each intermediate system (router)
- Application address
  - Process identifier assigned at destination host
  - i.e. TCP/IP port

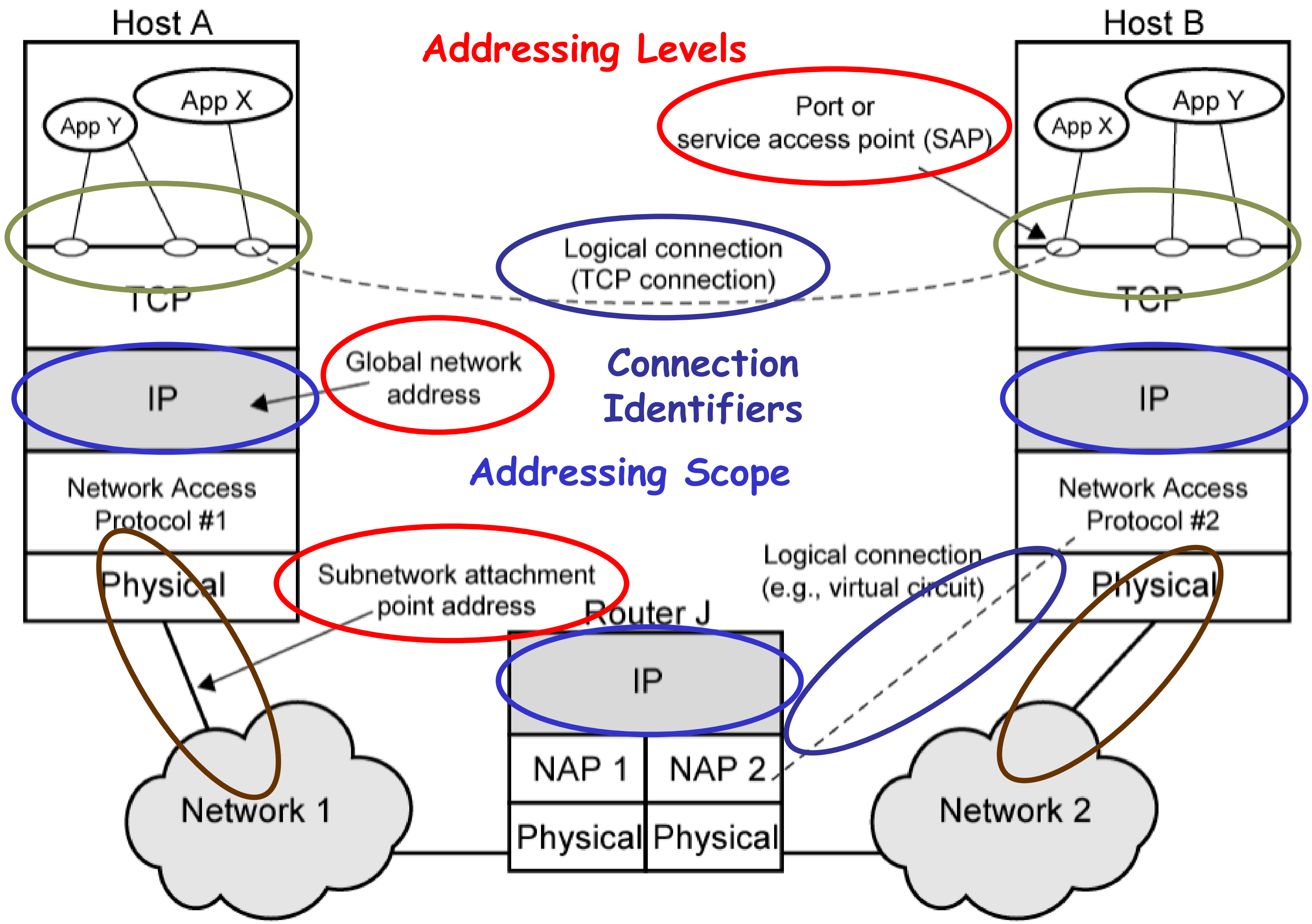
Addressing Scope

- Global address
  - Identifies host or router with global non-ambiguity
  - Synonyms permitted, i.e. a router may have more than one global address
- Network attachment address
  - Unique address for each device interface on specific network
  - e.g. *MAC* address on IEEE 802 network or *ATM* host address
- Port address
  - Above network level and unique within a system (router or host)
  - e.g. port 80 – web server listening port on TCP/IP
  - Need not be unique outside the single system

Addressing Mode

- Individual or Unicast address
  - Address referring to a single system or port
- Broadcast address
  - For all entities within a domain
- Multicast address
  - For specific subset of entities
- Anycast address
  - Any (suitable) entity within a subset

Level of Addresses



IP Operations

IP Operations

- Routing
- Datagram lifetime
- Fragmentation and re-assembly
- Error control
- Flow control

Routing

- Hosts and routers maintain routing tables
  - Indicate next router to which datagram should be sent
  - Static – may contain alternative routes
  - Dynamic – flexible response to congestion and errors
- Routing policy
  - Distance vector, Link state, Path vector
- Source routing
  - Source specifies route as sequential list of routers to be followed
- Route recording

Datagram Lifetime

- Datagrams may loop indefinitely
  - Routing based on obsolete networks information
  - TCP needs upper bound on datagram life
- Datagram marked with lifetime
  - Time To Live (TTL) field in IP
  - Once lifetime expires, datagram is discarded instead of forwarded
- Types of lifetime
  - Hop count – Decrement TTL on passing through each router

Fragmentation and Re-assembly

- Length of a packet exceeds the coming network's MTU (maximum transmission unit)

- When to fragment
  - Host – determine min of MTUs along the path
  - Router – fragment if the next MTU is exceeded

- When to re-assemble
  - Host – Packets getting smaller as data traverses internet
  - Router – infeasible since fragments may take different routes

Dealing with Failure

- Re-assembly may fail if some fragments get lost
- Re-assembly time out
  - Assigned when first fragment arrived
  - If timeout expires before all fragments arrive, discard partial data
- Use packet lifetime (TTL in IP)
  - Decrement with each fragment
  - If TTL runs out, kill partial data

Error Control

- Not guaranteed delivery
- Router should attempt to inform source if packet discarded
  - e.g. for checksum failure, TTL expiring
  - Datagram identification needed
- ICMP used to send error message
- Source may inform higher layer protocol

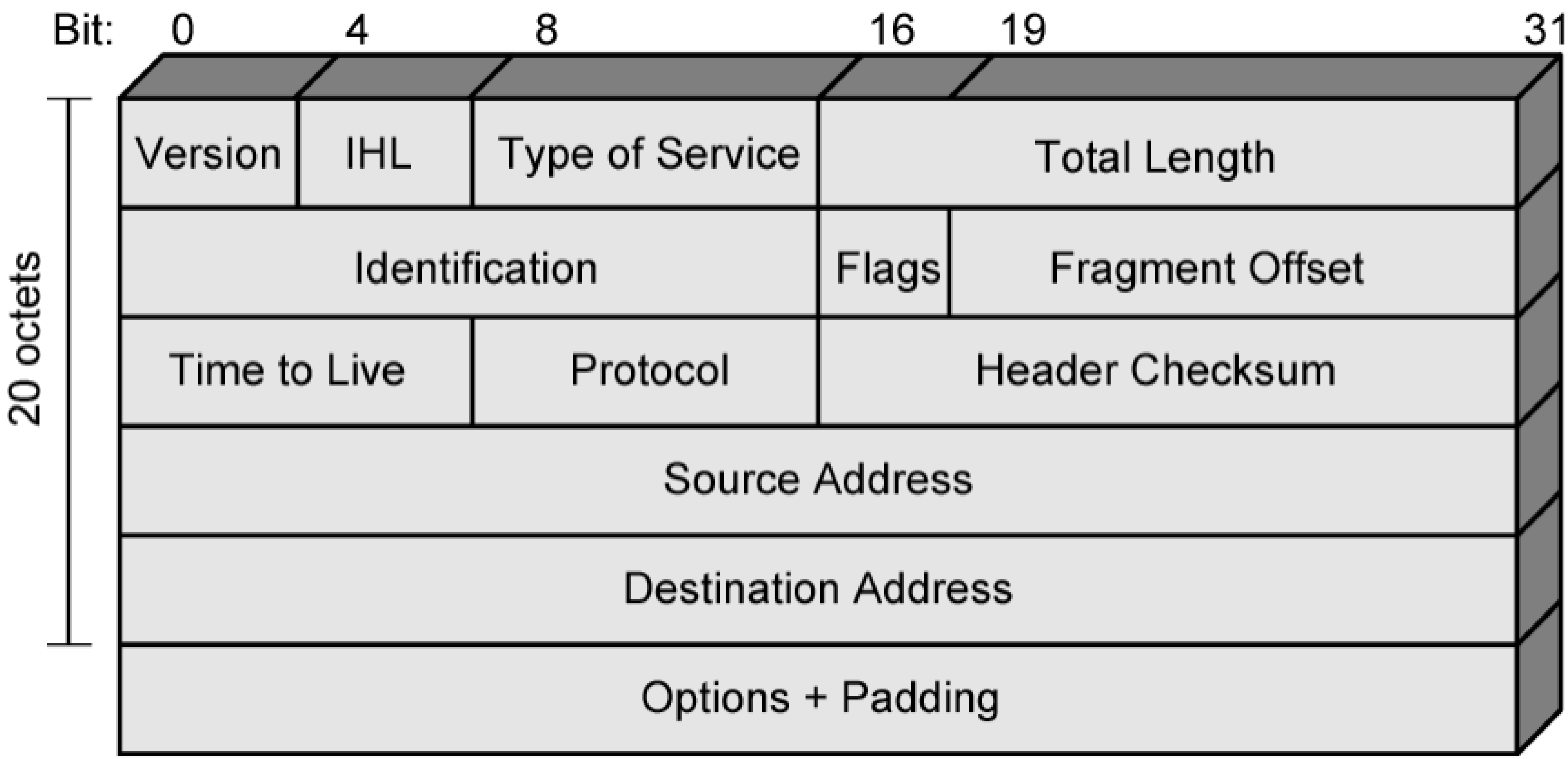
Flow Control

- Allows routers to limit rate of incoming data
  - Limited control functions in connectionless systems
  - New mechanisms coming soon

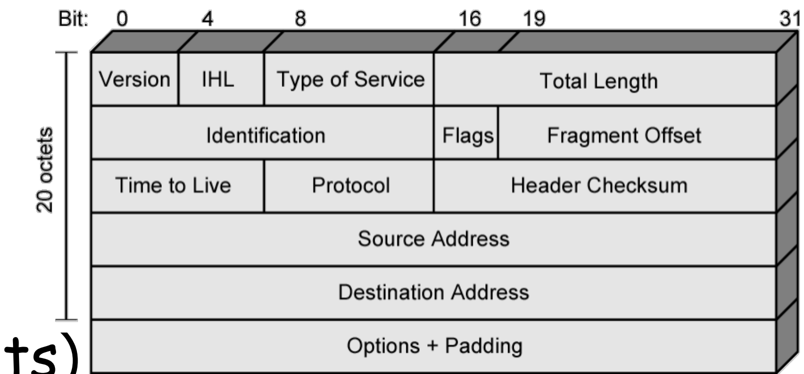
- Router discards incoming packets when buffer is full
  - May send source quench packets to sending host
  - Using ICMP

IP Packet Structure

IPv4 Header

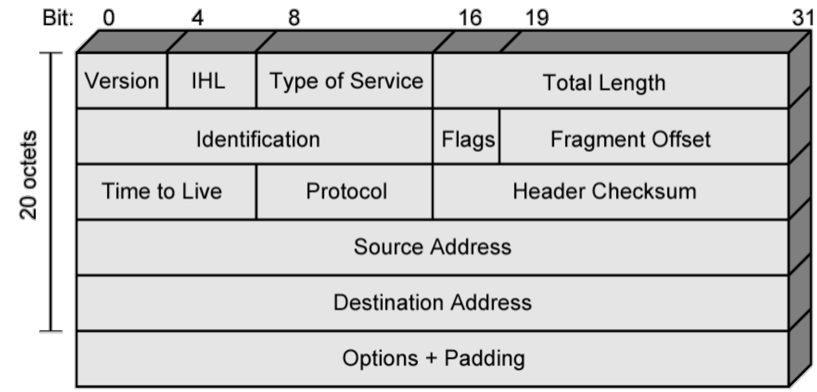

Bit:
0
4
8
16
19
31
Version
IHL
Type of Service
Total Length
Identification
Flags
Fragment Offset
Time to Live
Protocol
Header Checksum
Source Address
Destination Address
Options + Padding
20 octets

Header Fields (1)



- Version (4 bits)
  - Currently 4
  - IPv6 – see later
- Internet header length (IHL) (4 bits)
  - In 32 bit words (4 octets)
  - Minimum fixed header (20 octets) + options
- Type of service (8 bits)
  - Precedence
    - 3 bits, 8 levels defined
  - Reliability
    - 1 bit, Normal or high
  - Delay
    - 1 bit, Normal or low
  - Throughput
    - 1 bit, Normal or high

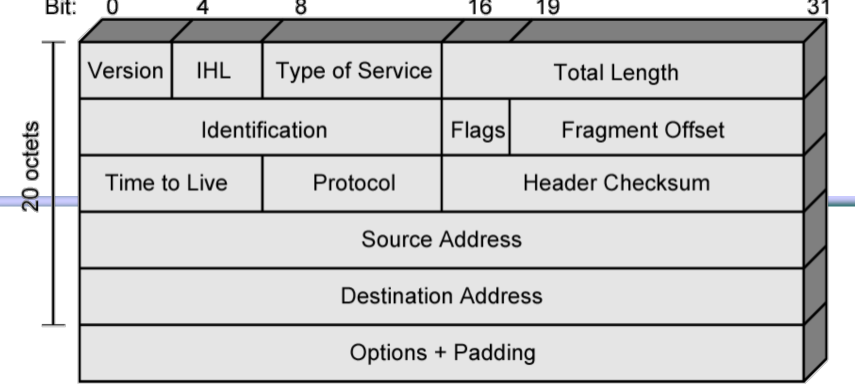
Header Fields (2)



- Total length (16 bits)
  - Of datagram, in octets
- Identification (16 bits)
  - Sequence number
  - Used with addresses and user protocol to identify datagram uniquely
- Flags (3 bits)
  - More flag, Don’t fragment
- Fragmentation offset (13 bits)
- Time to live (8 bits)
- Protocol (8 bits)
  - Next higher layer to receive data field at destination

指示传输层的协议类型（TCP或UDP）

Header Fields (3)



- Header checksum (16 bits)
  - Complement sum of all 16 bit words in header
  - If not correct, router discards packets
  - Reverified and recomputed at each router, set to 0 during calculation. (Why?)

- Source address (32 bits)
- Destination address (32 bits)

- Options (variable ≤ 40 octets)
- Padding (variable)
  - To fill to multiple of 32 bits long

Data Field

- Carries user data from next layer up
- Multiple of 8 bits long (i.e. octet)

- Max length of datagram (header + data) 65,535 octets

IP Primitives

2 primitives

- Send (called by upper layer)
  - Request transmission of data unit
- Deliver (notify upper layer)
  - Notify user of arrival of data unit
- Parameters
  - Used to pass data and control info

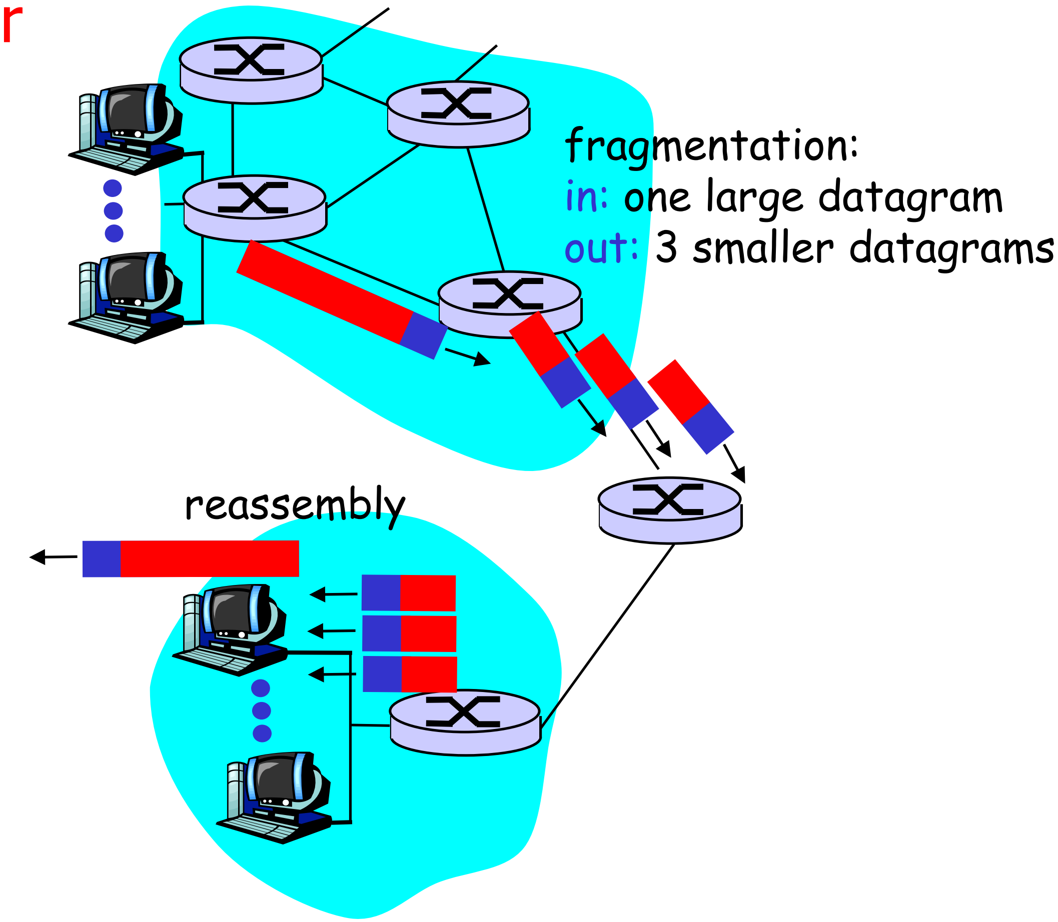
Dealing with Fragmentation

A closer look at fragmentation

- Every link has a "Maximum Transmission Unit" (MTU)
  - Largest number of bits it can carry as one unit
- A router can split a packet into multiple "fragments" if the packet size exceeds the link's MTU
- Must reassemble to recover original packet

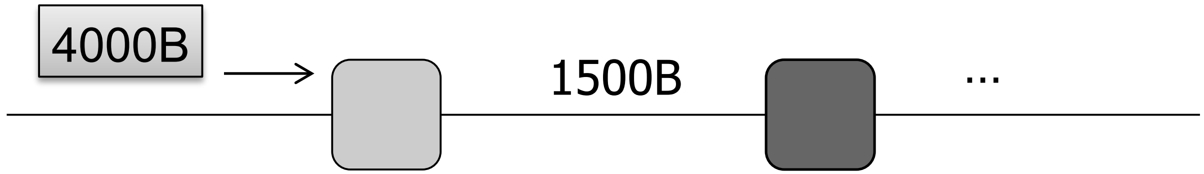
IP Fragmentation

- IPv4 fragments at router
  - One datagram becomes several datagrams
  - IP header bits used to identify, order related fragments
- IP re-assembles at destination only



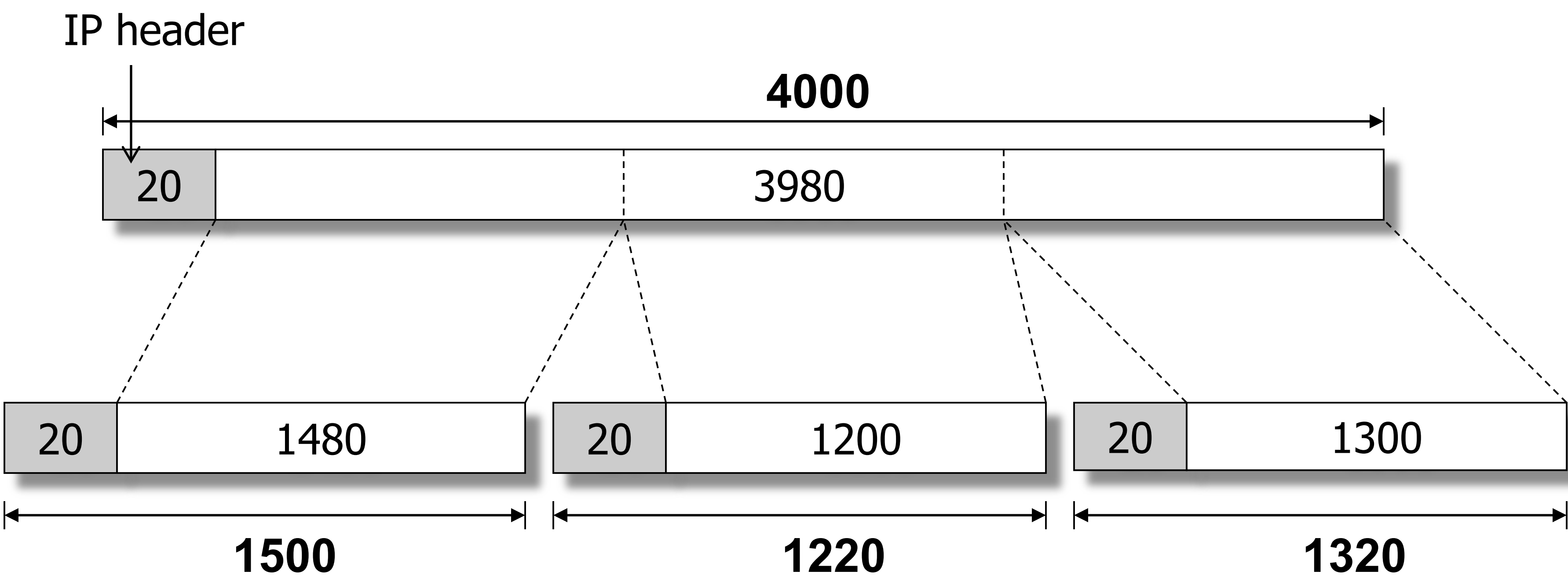
Example of fragmentation

- A 4000 byte packet crosses a link w/ MTU=1500B

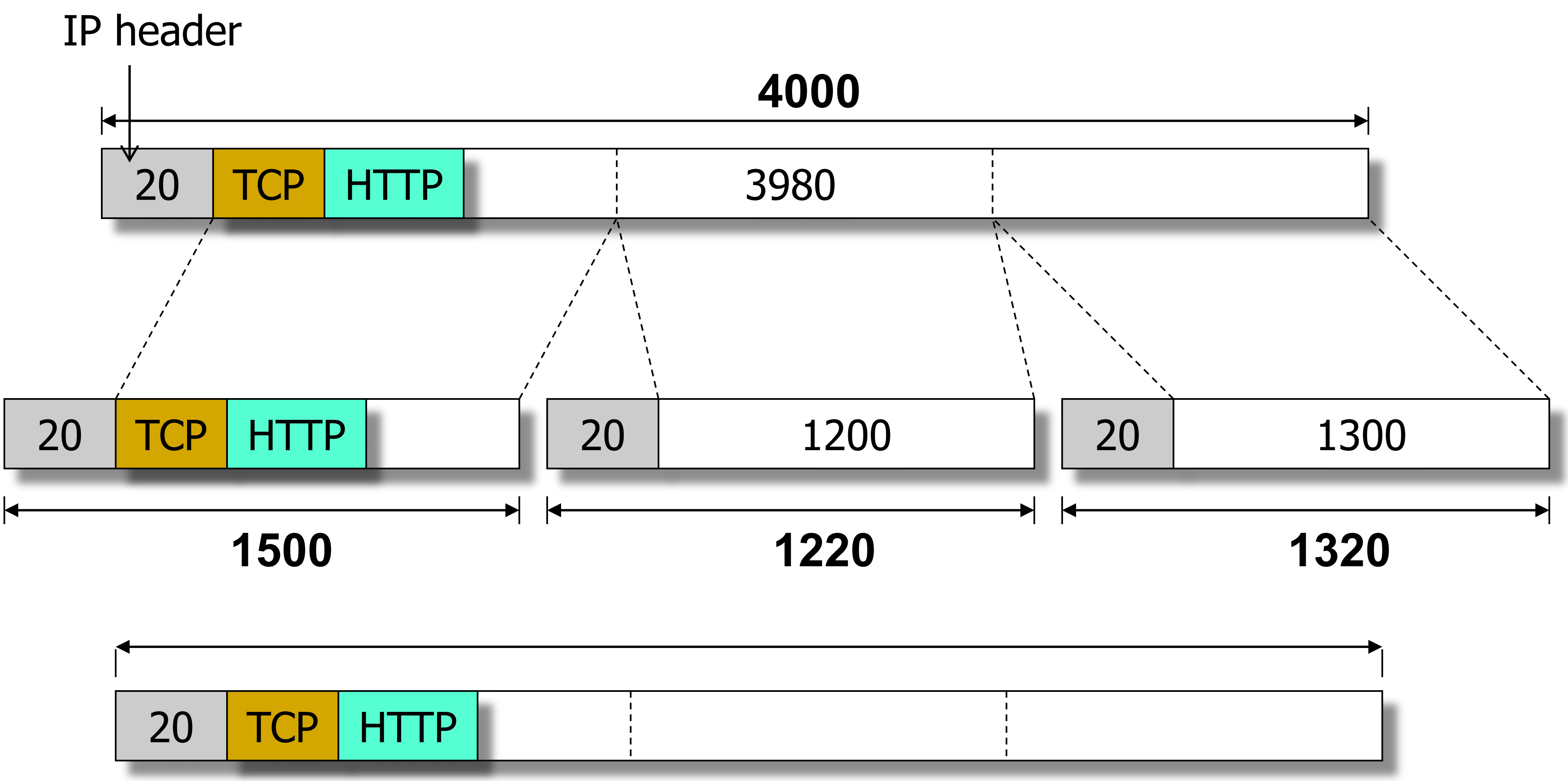


Example of fragmentation

- A 4000 byte packet crosses a link w/ MTU=1500B



Why reassemble?



Must reassemble before sending the packet to the higher layers!

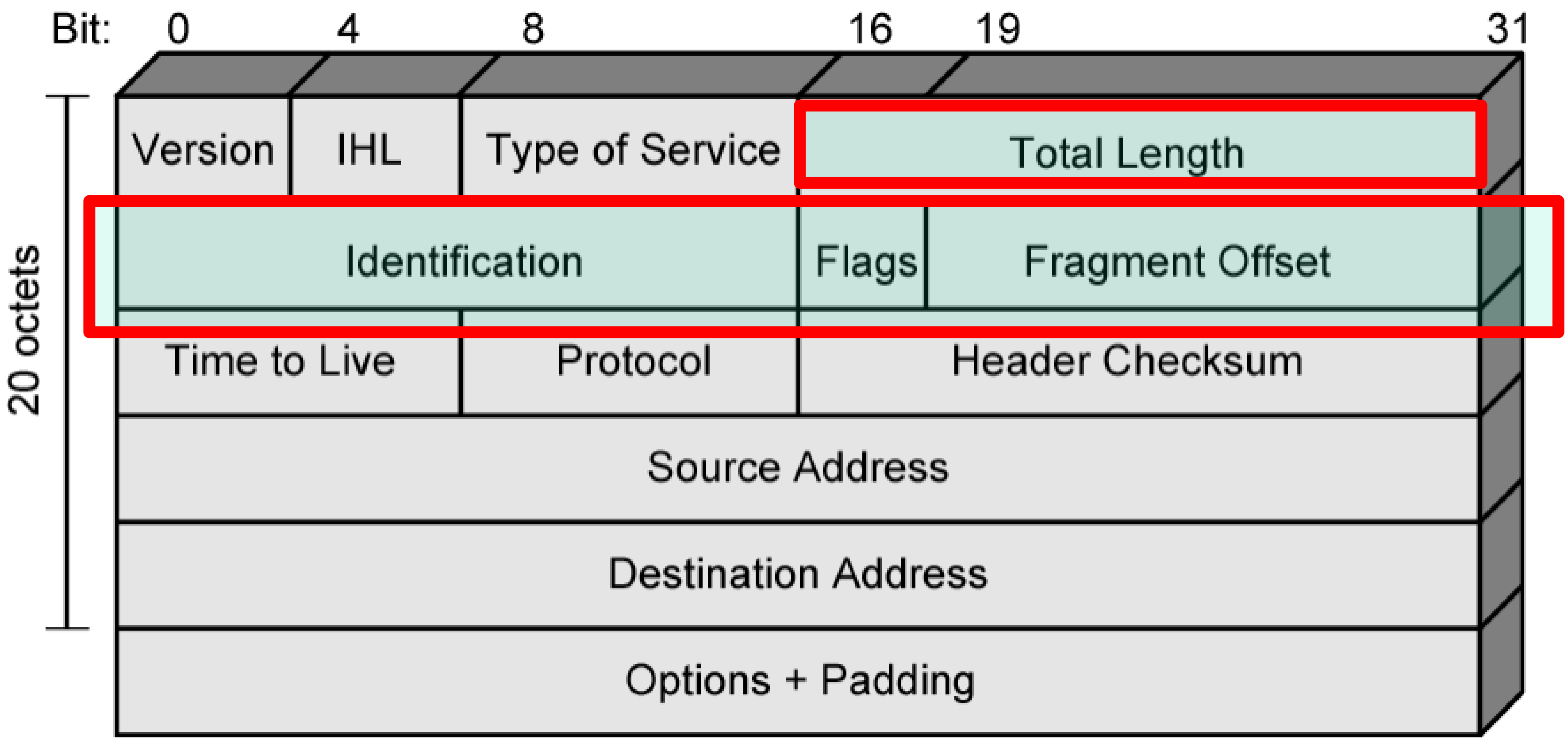
Reassembly: What fields?

- Need a way to identify fragments of the packet
  - Introduce an identifier
- Fragments can get lost
  - Need some form of sequence number or offset
- Sequence numbers / offset
  - How do I know when I have them all? (need max seq# / flag)
  - What if a fragment gets re-fragmented?

IP Fragmentation Fields

- Data Unit Identifier (ID)
  - Identifies end system originated datagram, also needs:
  - Source and destination address, Upper layer (e.g. TCP)
- Data length
  - Length of user data in octets including header
- Offset
  - Position of fragment of user data in original datagram
  - In multiples of 64 bits (i.e. 8 octets)
- More flag
  - Indicates that this is not the last fragment

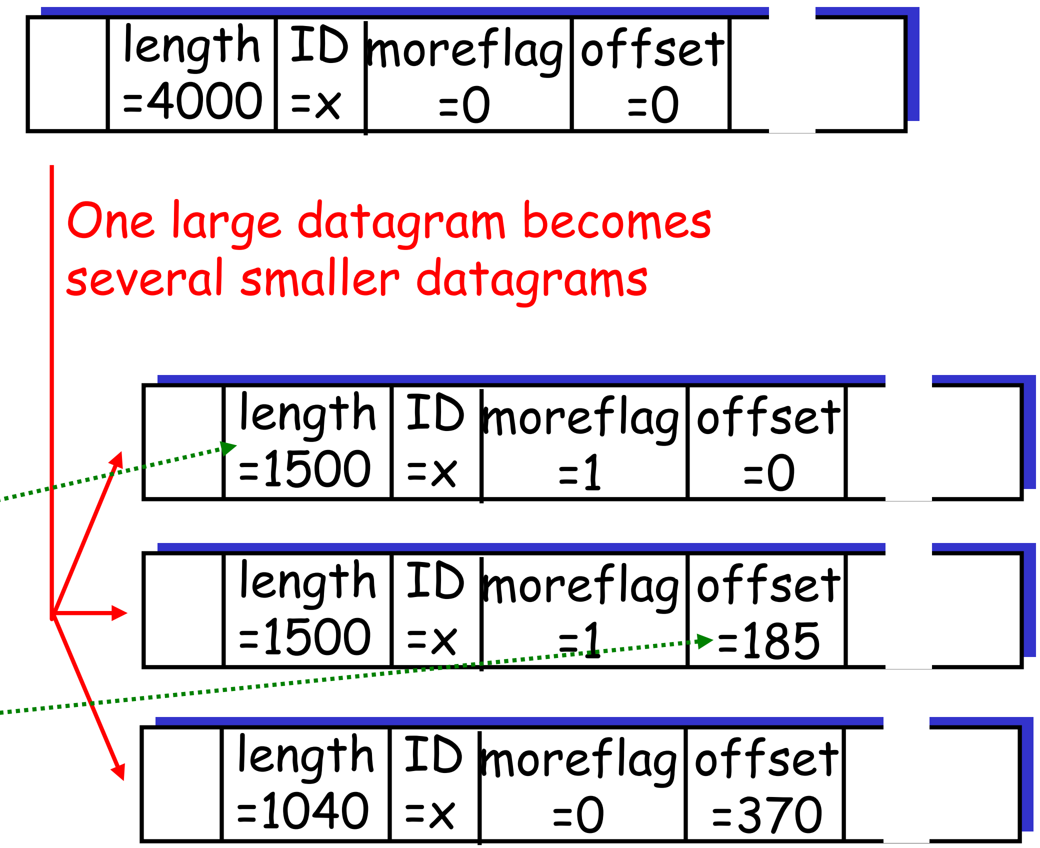
IP Field for Fragmentation



Fragmentation Example

Example

- 4000 octets datagram (3980 data + 20 header)
- MTU = 1500 octets



1480 bytes in data field

offset = 1480/8

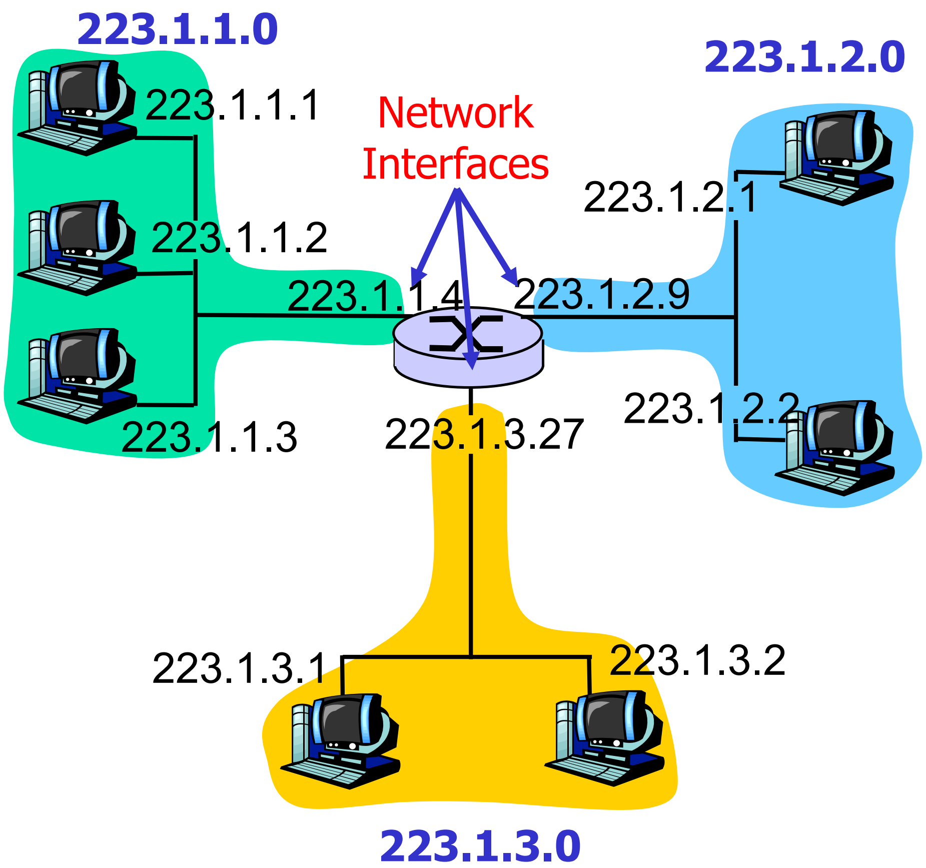
Datagram Re-assembly

- Must prepare enough buffer space at reassembly point
- As fragments with the same ID arrive, data are inserted in proper position in the buffer
  - Use *Length* and *Offset* header fields
  - Use *More flag* to determine if end fragment arrived
- Until entire data field is reassembled
  - Starting with an *Offset* of 0 and ending with a false *More flag*

IP Address

IP Addressing

- IP address
  - 32 bit global internet address for each interface
  - Network part (high order bits)
  - Host part (low order bits)
- Physical network (from IP perspective)
  - Can reach each other without intervening router

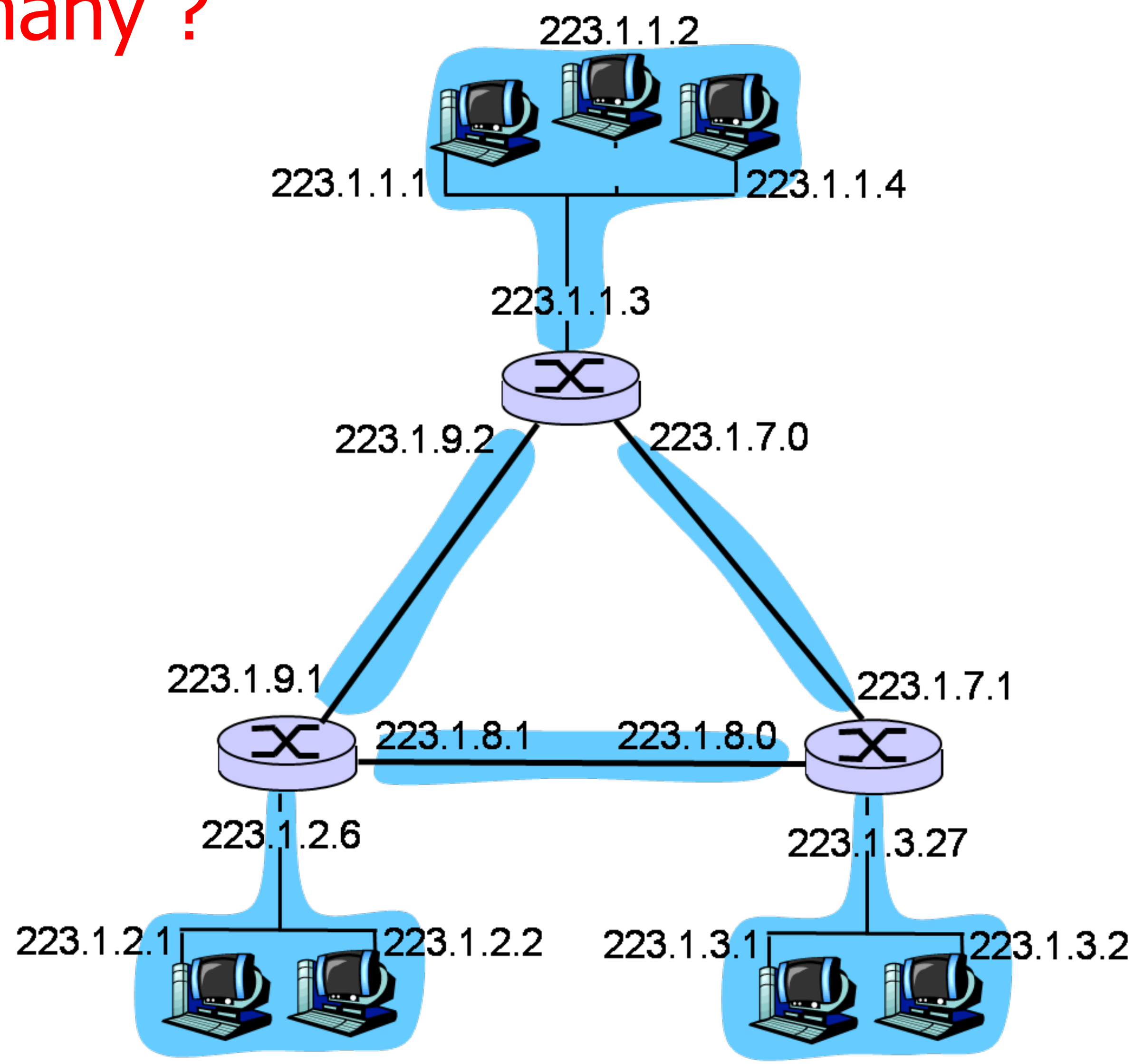


223.1.1.1 = 11011111 00000001 00000001 00000001

223 1 1 1

Count the Physical Networks

- How many ?

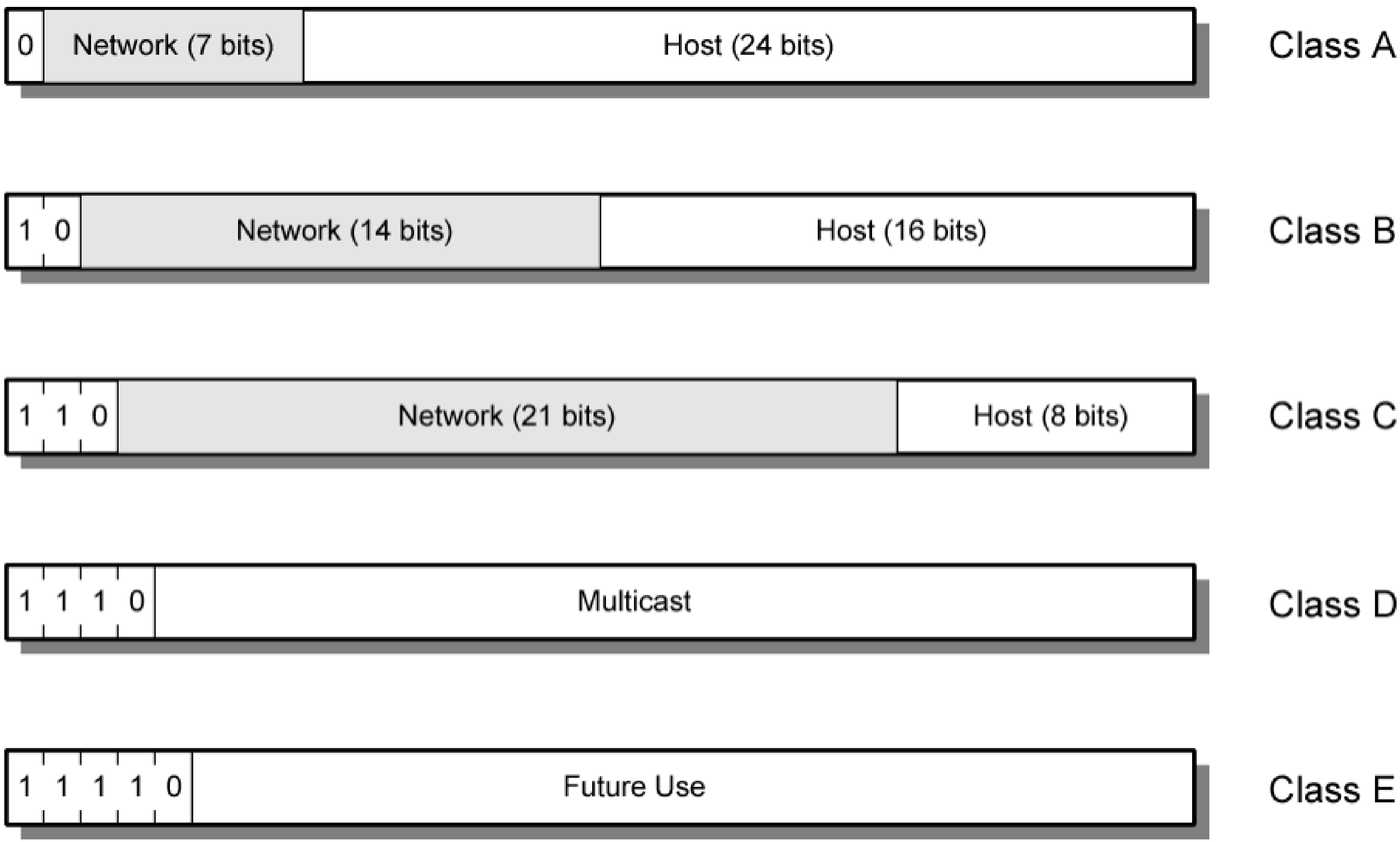


IP Address

- A separate address is required for each physical interface of a host/router to a network
  - Facilitates routing
- Use Dotted-Decimal Notation

- netid unique & administered by
  - American Registry for Internet Numbers (ARIN)
  - Reseaux IP Europeens (RIPE)
  - Asia Pacific Network Information Centre (APNIC)
- hostid assigned within designated organization

IPv4 Address Formats



IP Addresses – Class A

0	Network (7 bits)	Host (24 bits)	Class A

A类地址：
首位为0；
支持$2^7-2=126$个网段；
每个网段支持主机数为$2^{24}-2$ =16777214（全0和全1的地址要扣除，全0是网络号，全1是广播号）

- Start with binary 0
- Reserved netid
  - All 0 reserved
  - 01111111 (127) reserved for loopback
- Range 1.x.x.x to 126.x.x.x
- Up to 16 million hosts

127.*.*.*: 回环测试，用于测试本地网卡。127.0.0.1 “localhost”

- All allocated

IP Addresses – Class B

Class B

- Start with 10
- Range 128.0.x.x to 191.255.x.x
- Second Octet also included in network address

- 2^{14} = 16,384 class B networks
- Up to 65,000 (=2^{16}-2) hosts

- All allocated

IP Addresses – Class C

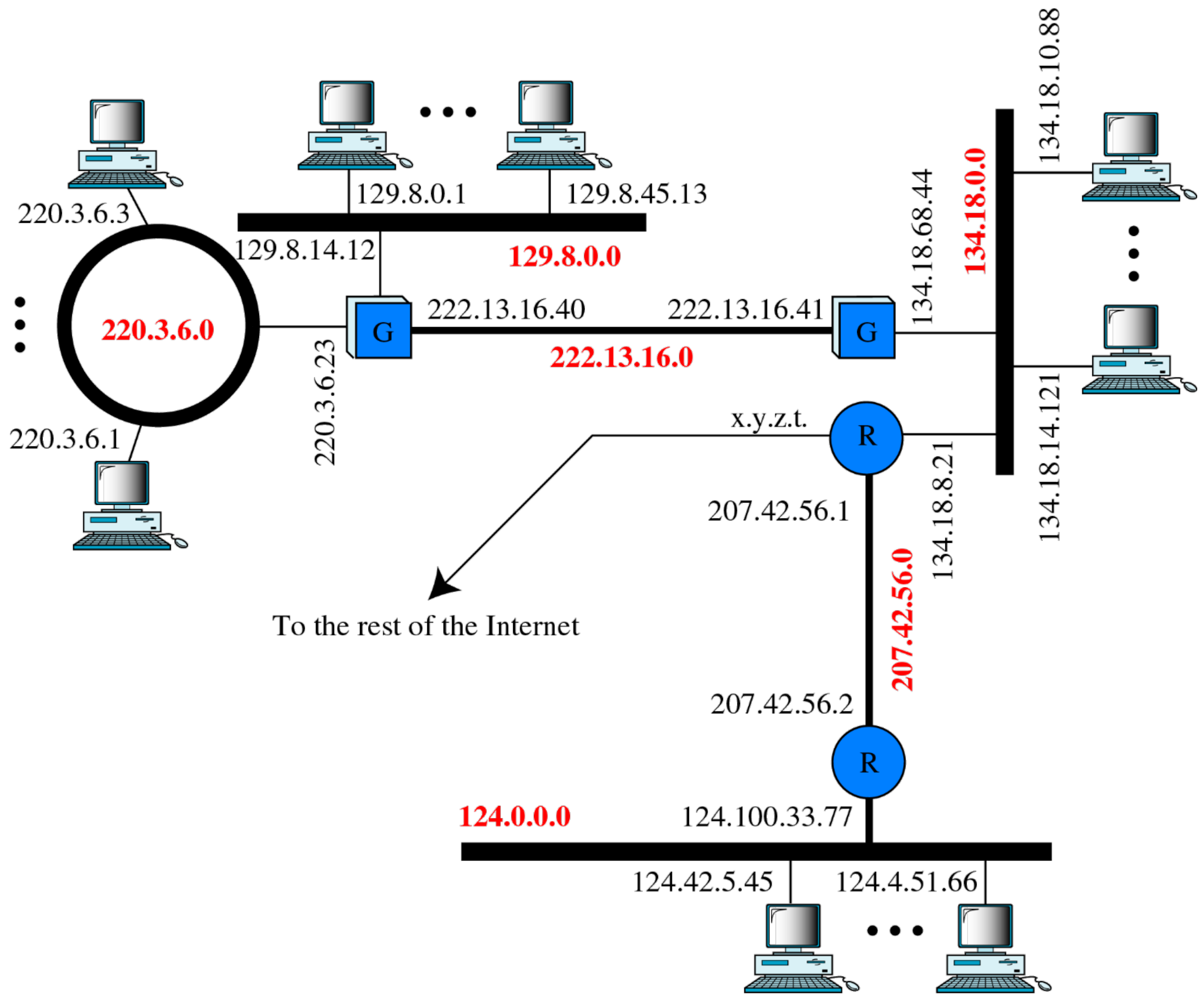
Class C

- Start with 110
- Range 192.0.0.x to 223.255.255.x
- Second and third octet also part of network address

- 2^{21} = 2,097,152 networks
- Up to 254 (=2^8-2) hosts

- Nearly all allocated

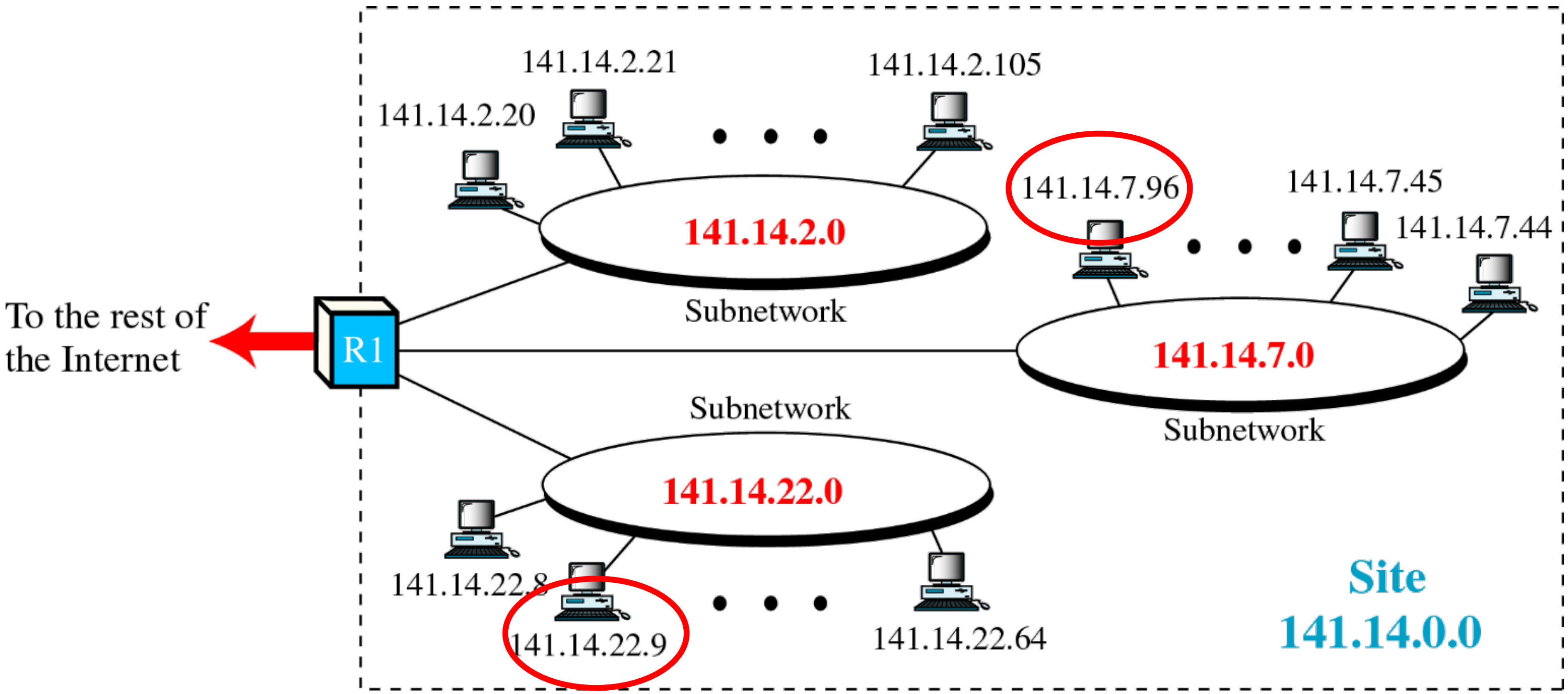
Inter-Networks with Addresses



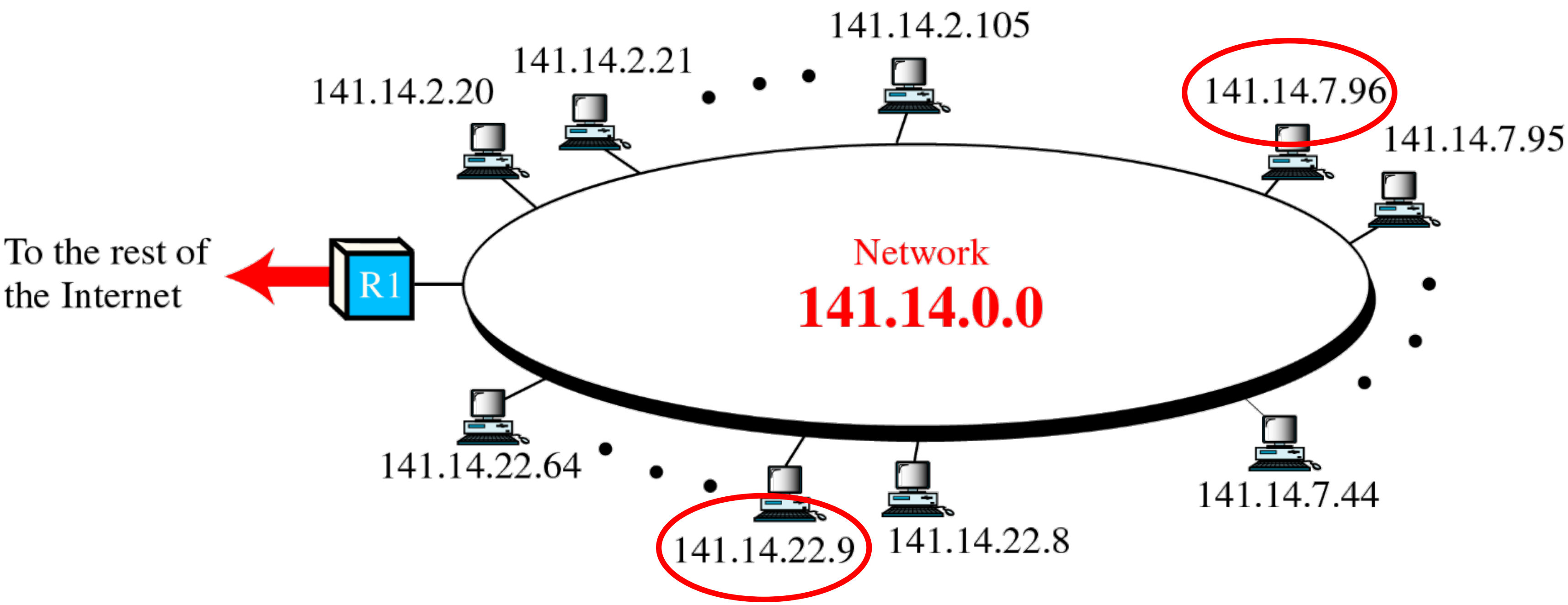
Subnets and Subnet Masks

- Handle problem of network address inadequacy
- Host portion of address partitioned into subnet number and host number
  - Subnet mask indicates which bits are subnet number and which are host number
  - Each LAN assigned a subnet number, more flexibility
  - Local routers route within subnetted network
- Subnets looks to rest of internet like a single network
  - Insulate overall Internet from growth of network numbers and routing complexity

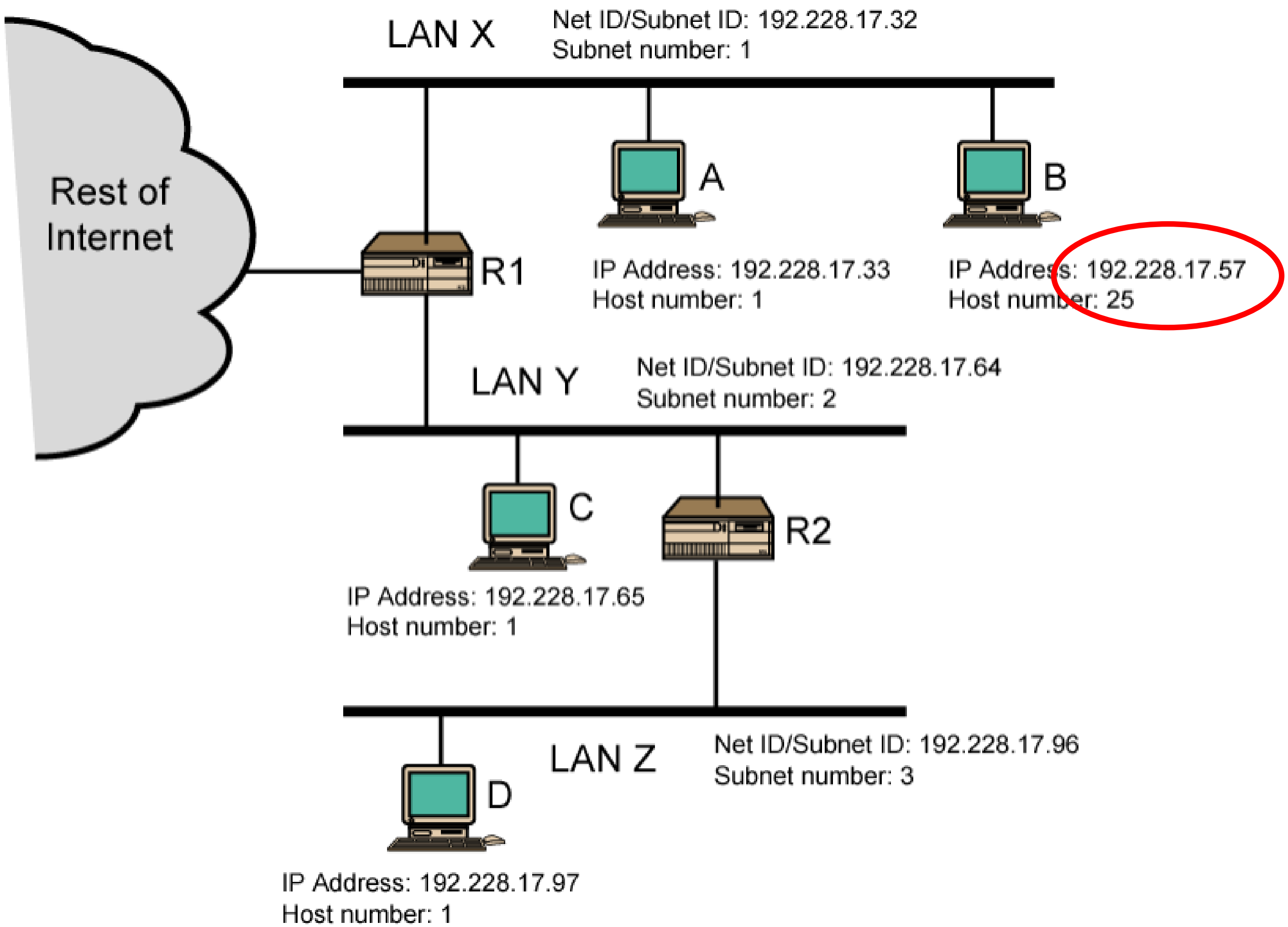
Subnets Example



Subnets to the Rest



Routing Using Subnets (1)



Routing Using Subnets (2)

(a) Dotted decimal and binary representations of IP address and subnet masks

	Binary Representation	**Dotted Decimal**
IP address	11000000.11100100.00010001.00111001	192.228.17.57
Subnet mask	11111111.11111111.11111111.11100000	255.255.255.224
Bitwise AND of address and mask (resultant network/subnet number)	11000000.11100100.00010001.00100000	192.228.17.32
Subnet number	11000000.11100100.00010001.001	1
Host number	00000000.00000000.00000000.00011001	25

(b) Default subnet masks

	Binary Representation	**Dotted Decimal**
Class A default mask	11111111.00000000.00000000.00000000	255.0.0.0
Example Class A mask	11111111.11000000.00000000.00000000	255.192.0.0
Class B default mask	11111111.11111111.00000000.00000000	255.255.0.0
Example Class B mask	11111111.11111111.11111000.00000000	255.255.248.0
Class C default mask	11111111.11111111.11111111.00000000	255. 255. 255.0
Example Class C mask	11111111.11111111.11111111.11111100	255. 255. 255.252

CIDR Notation

- Classless Inter Domain Routing (CIDR)
  - An IP address is represented as "A.B.C.D/n", where n is called the IP (network) prefix

IP Address	10	217	123	7
	00001010	11011001	01111011	00000111
Subnet	255	255	240	0
	11111111	11111111	11110000	00000000
Network ID	00001010	11011001	01110000	00000000
CIDR	10.217.112.0/20			

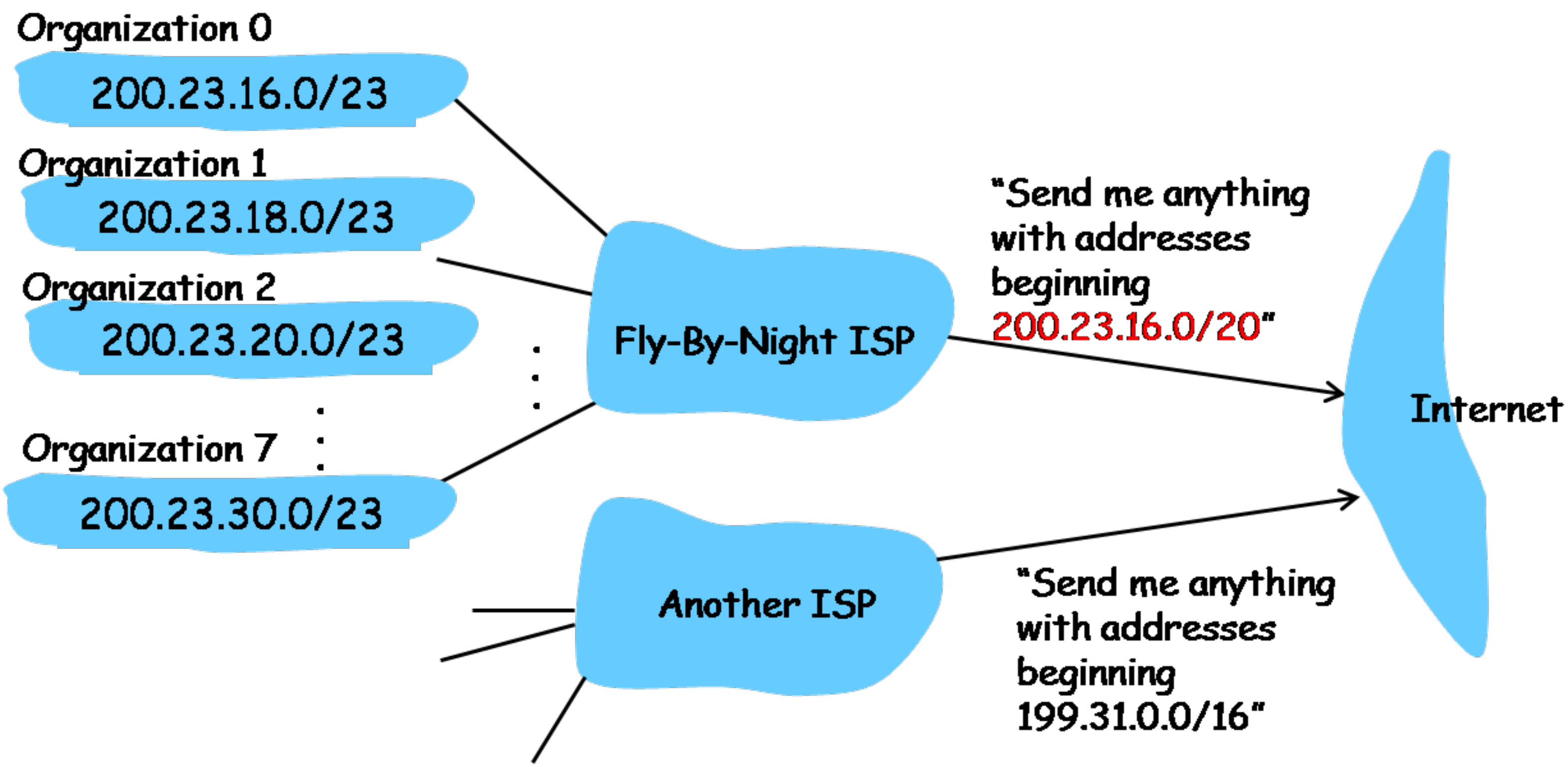
More General Case

- An ISP can be looked as a set of subnets
  - Support many organizations (Intranets)
  - Hierarchical addressing

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

Route Aggregation

- Allows efficient advertisement of routing information



Summary

- IP Operations
- IPv4包头格式
- IP地址及分配（A类，B类，C类）
  - 子网掩码
  - CIDR地址表示
  - 如何进行子网划分

Homework

- 第四章：R25, P8, P12