Chapter 4: Network Layer

Network Layer Address

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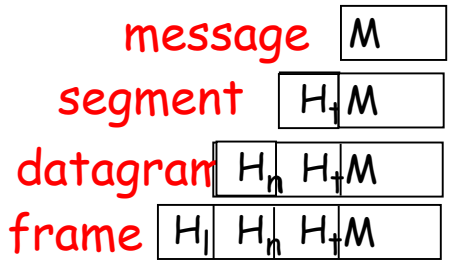
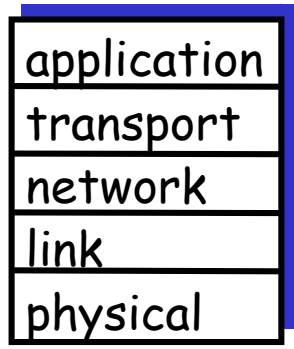
Communication through Layers and Nodes

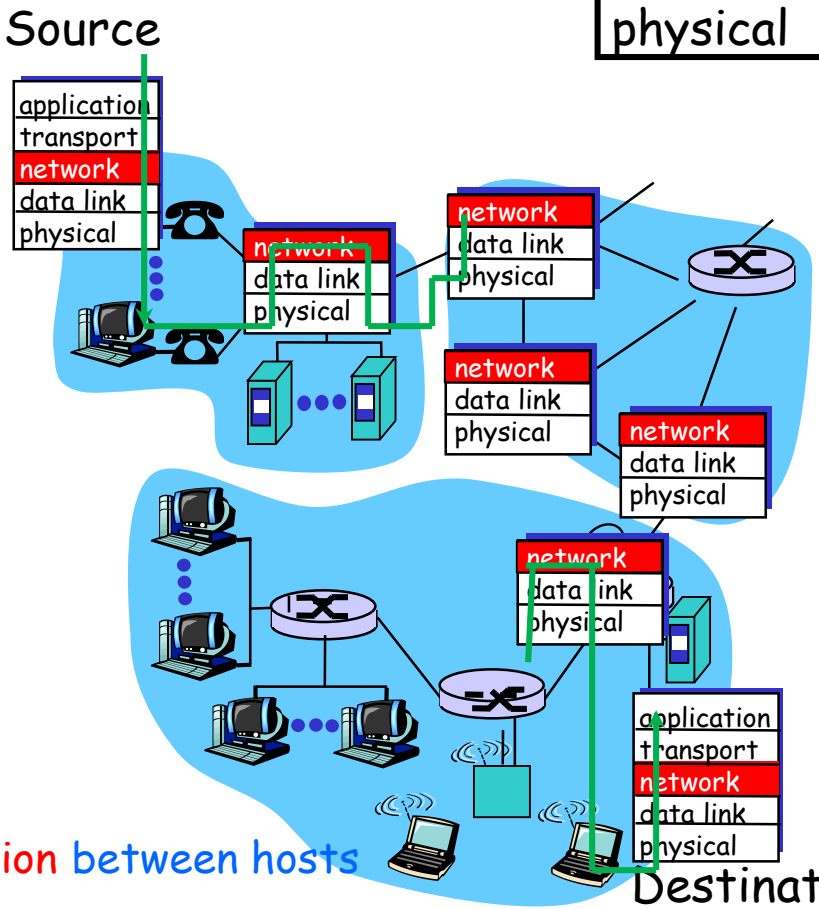
How does network layer datagram travel from sending host to receiving host ?

- sender side: network layer takes segments from the transport layer, encapsulates each segment into a datagram (the name of network-layer packet), passes to the link layer.
- Intermediate routers: datagrams are routed through intermediate nodes (routers)
- receiver side: receives the datagram from lower layer, extracts segment and passes to the transport layer.

Encapsulation



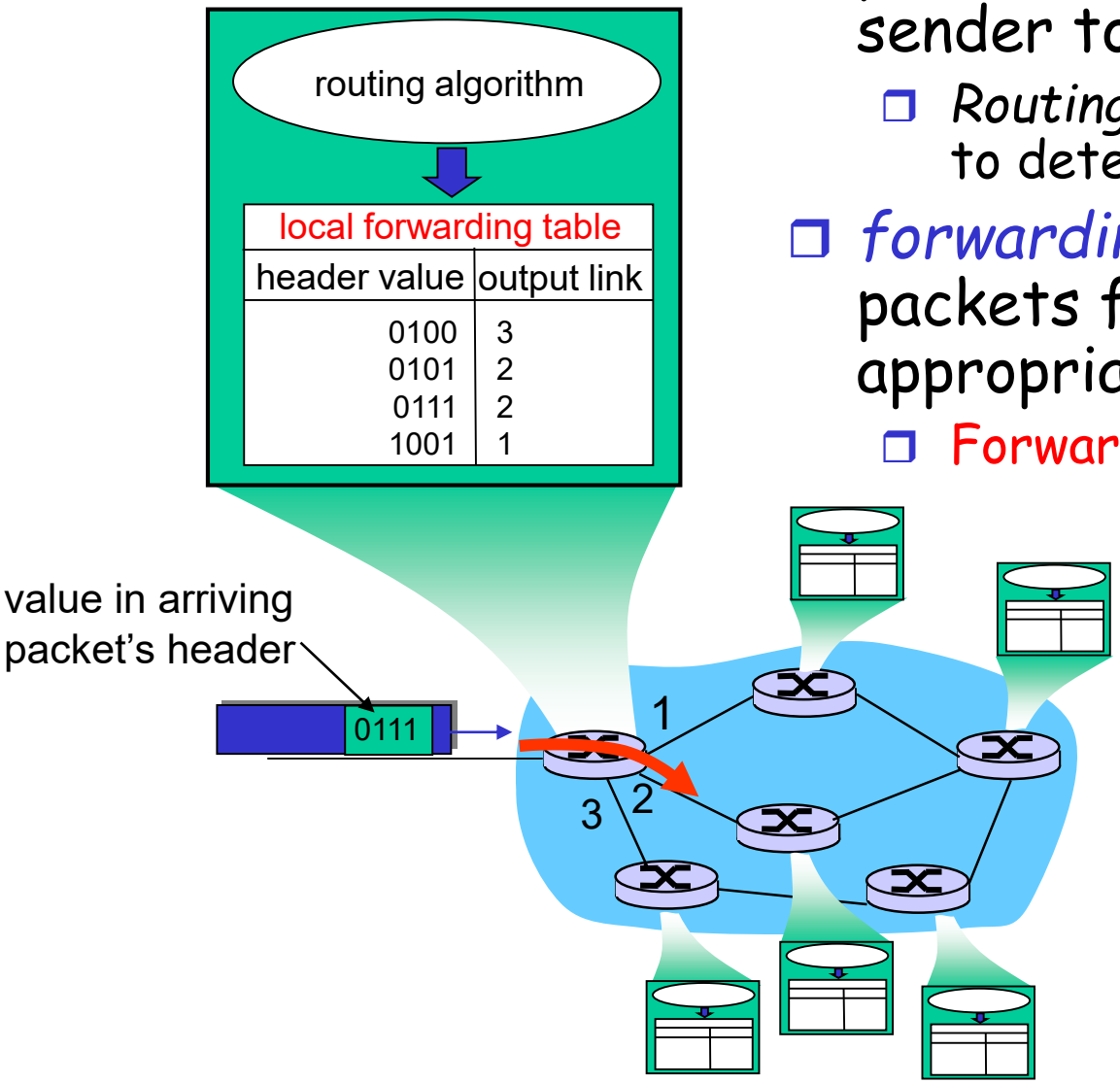




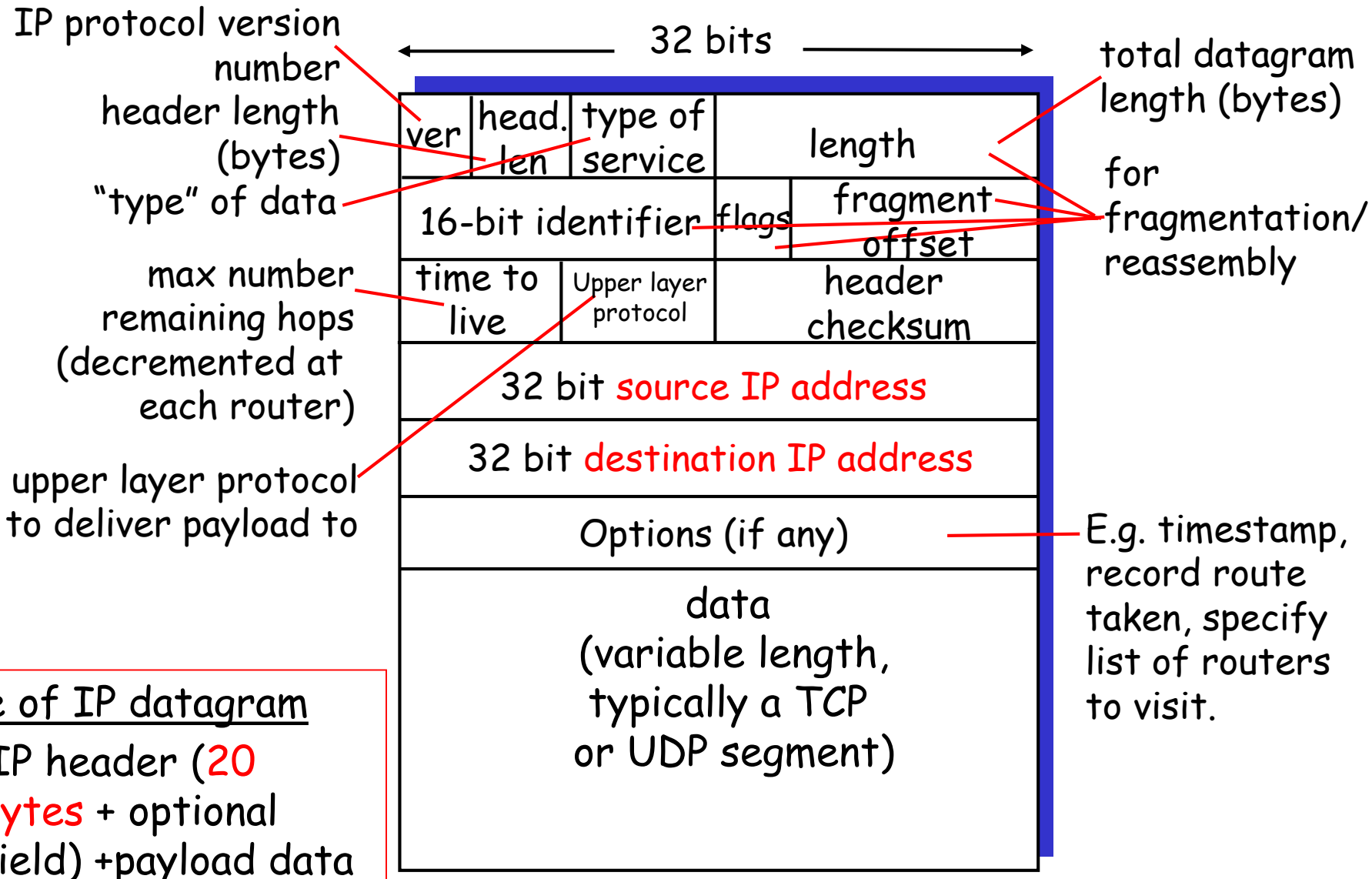
Network layer protocols provide logical communication between hosts

Key Network-Layer Functions

- *routing:* determine the path of packets as they flow from a sender to a receiver
  - *Routing algorithm:* run at routers to determine the path of packets
- *forwarding:* move network layer packets from router's input to appropriate router output
  - Forwarding table



IP datagram format (IPV4)



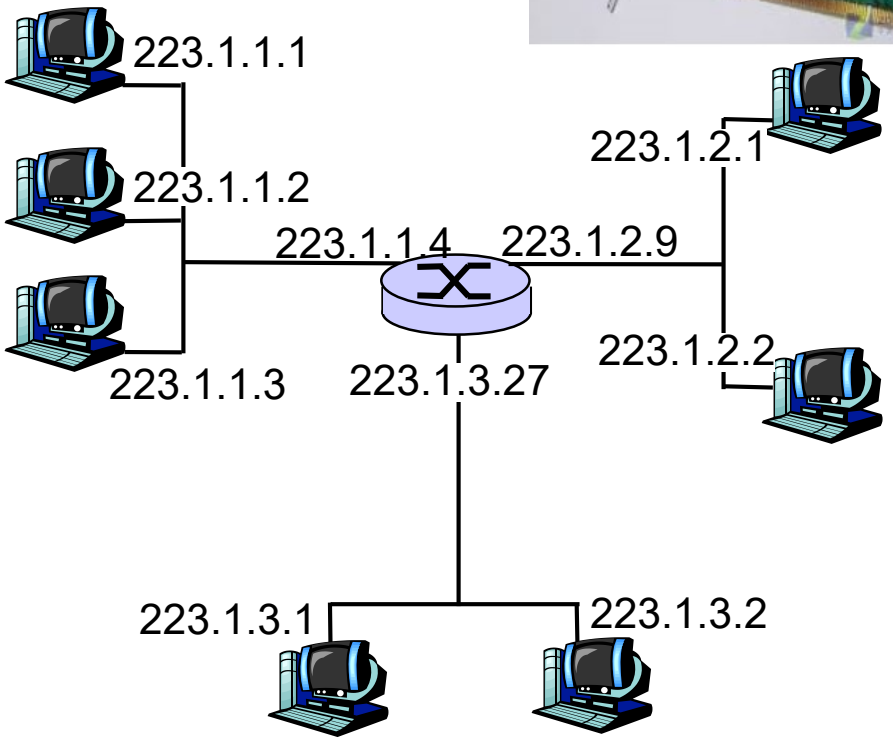
Size of IP datagram

- IP header (20 bytes + optional field) +payload data

IP Addressing—Network Layer Address

IPv4 Addressing: introduction

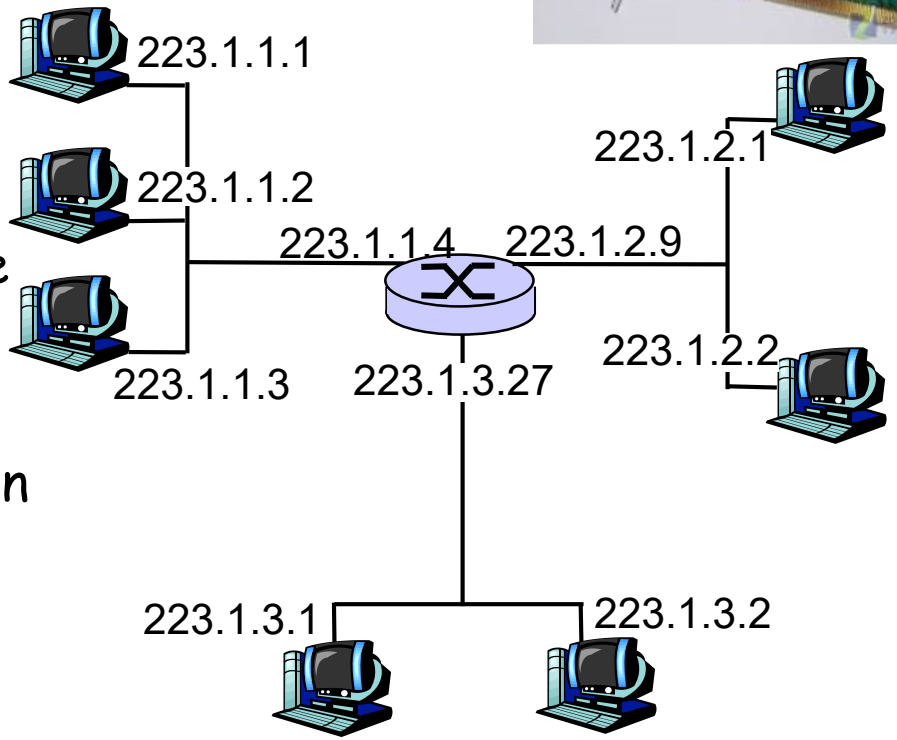
- *interface:* connection between host/router and a physical link (sometimes called a "port").
  - A host typically has one interface
  - A router typically has multiple interfaces



- IP address
  - Each interface on every host and router in the Internet must have a globally unique IP address.
  - IP address is associated with each interface, rather than the host or router containing that interface.
  - A router usually has multiple IP addresses, each of IP addresses corresponds to each of its interfaces
  - A host usually has one interface, therefore, we can say the IP address of the host.

IPv4 Addressing: introduction

- IP address:
  - Binary representation: 4-byte IP address
  - Dotted decimal representation
  - Two levels of hierarchy structure

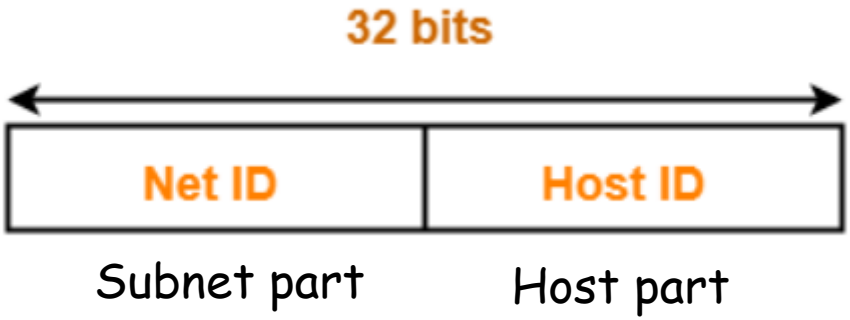


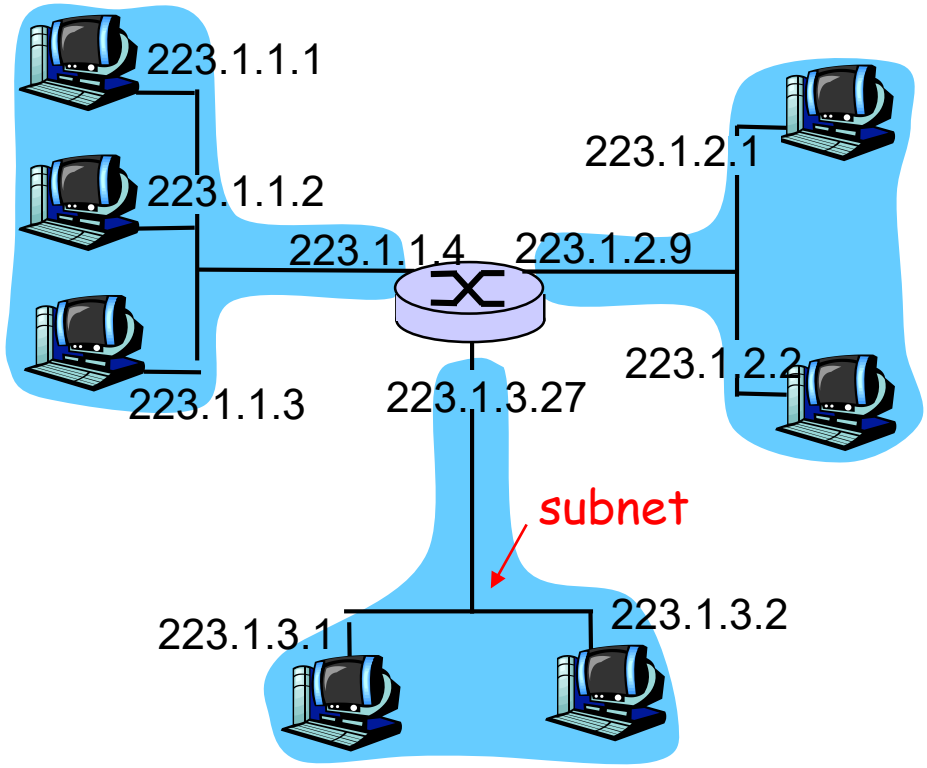
223.1.1.1 = 11011111 00000001 00000001 00000001

223 1 1 1

IP Address Format

- The structure of IP address:
  - Network ID: subnet part (high order bits)
  - Host ID: host part (low order bits)

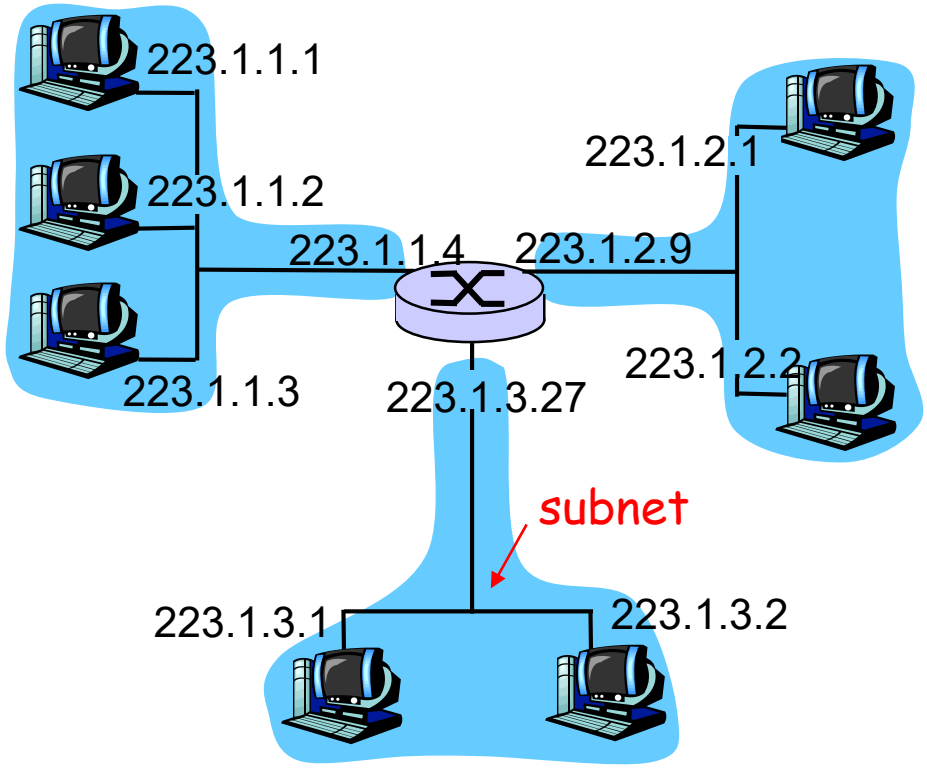




network consisting of 3 subnets

- *What's a subnet ?*
  - A subnet is a network where interfaces can physically reach each other without intermediate router.

Subnets



network consisting of 3 subnets

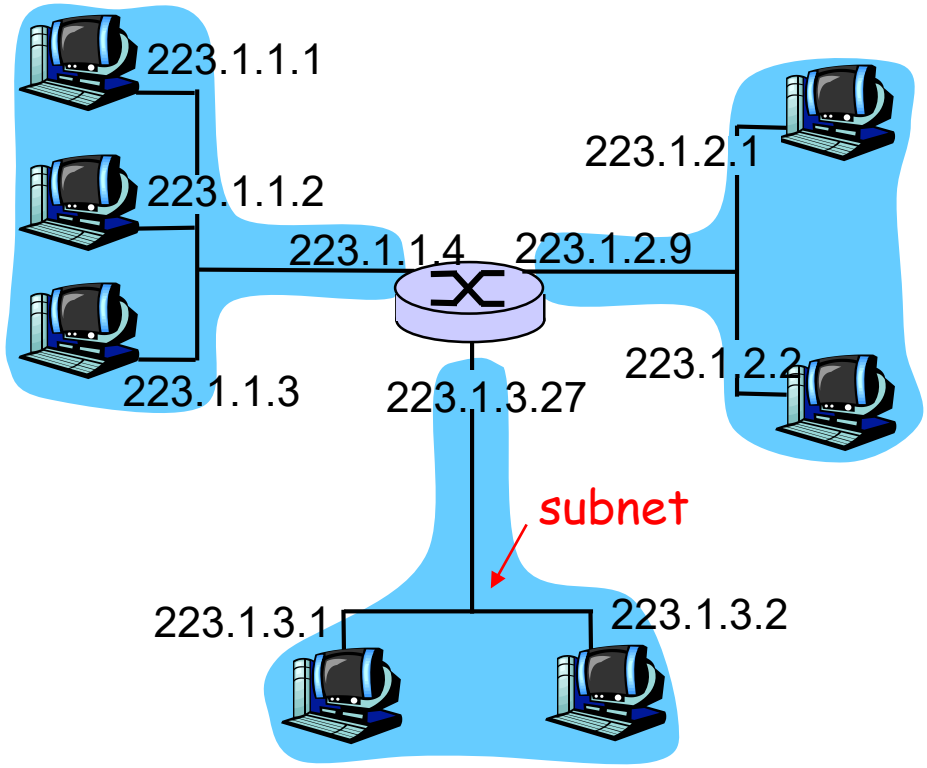
- *IP address of subnet*
  - Dotted-decimal notation: a.b.c.d/x, where the notation /x indicates that left x most bits of the 32-bit IP address is the subnet part, and remaining (32-x) bits is the host part
  - Interfaces in the same subnet have the same subnet part of IP address
  - Example: the above network includes three subnets with subnet mask /24.

Subnets

- Subnet mask is also expressed in decimal notation like an address, like 255.255.0.0

- /x means that, in the subnet mask, the left most x bits are 1s, the other bits are 0.

- For example, /24 means that Subnet mask is 255.255.255.0.



network consisting of 3 subnets

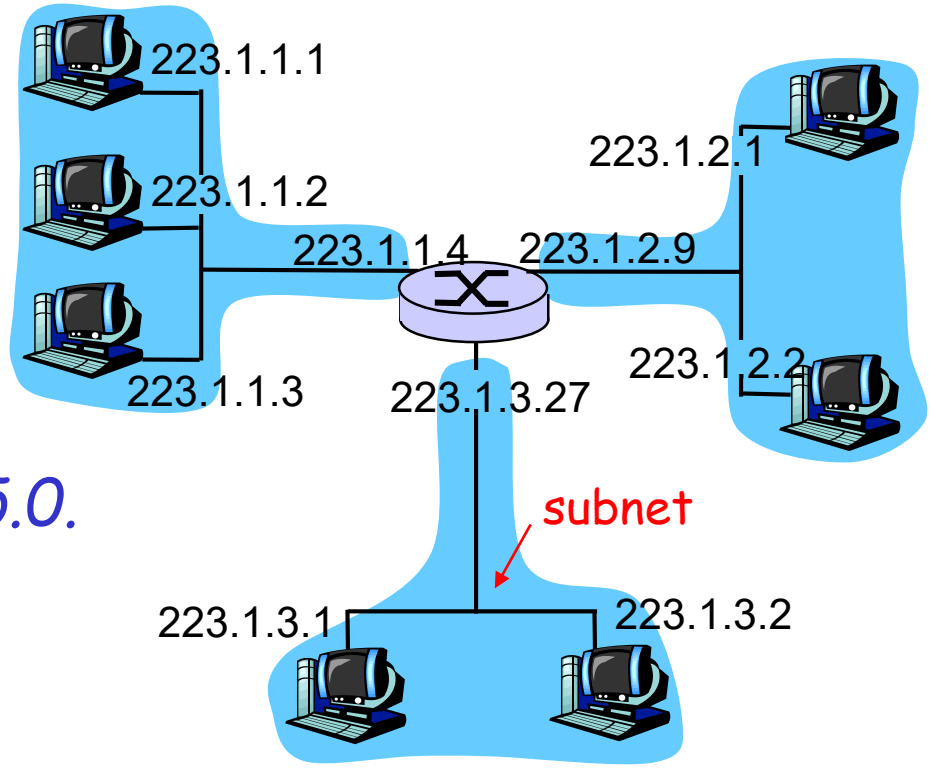
Network Address

- IP address is 192.168.10.2 (11000000 10101000 00001010 00000010), subnet mask is 255.255.255.240 (11111111 11111111 11111111 11110000),
- Network address and host address:

IP Address	11000000 10101000 00001010 00000010
Subnet mask	11111111 11111111 11111111 11110000
AND Network Address	11000000 10101000 00001010 00000000
Host Address	00000000 00000000 00000000 00000010

Network address: 192.168.10.0; Host address: 0.0.0.2

Exercise

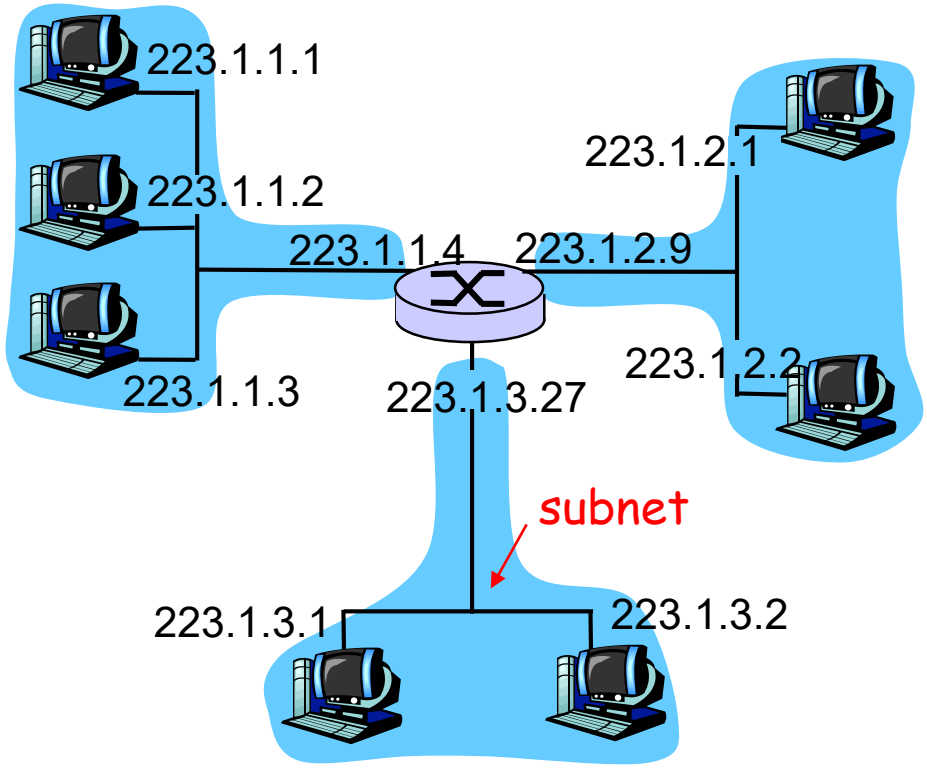


network consisting of 3 subnets

- *Subnet mask is 255.255.255.0.*
- *Write down the network address and host address*

IP address	Network address	Host address
223.1.3.1		
223.1.3.26		
223.1.3.2		

Exercise



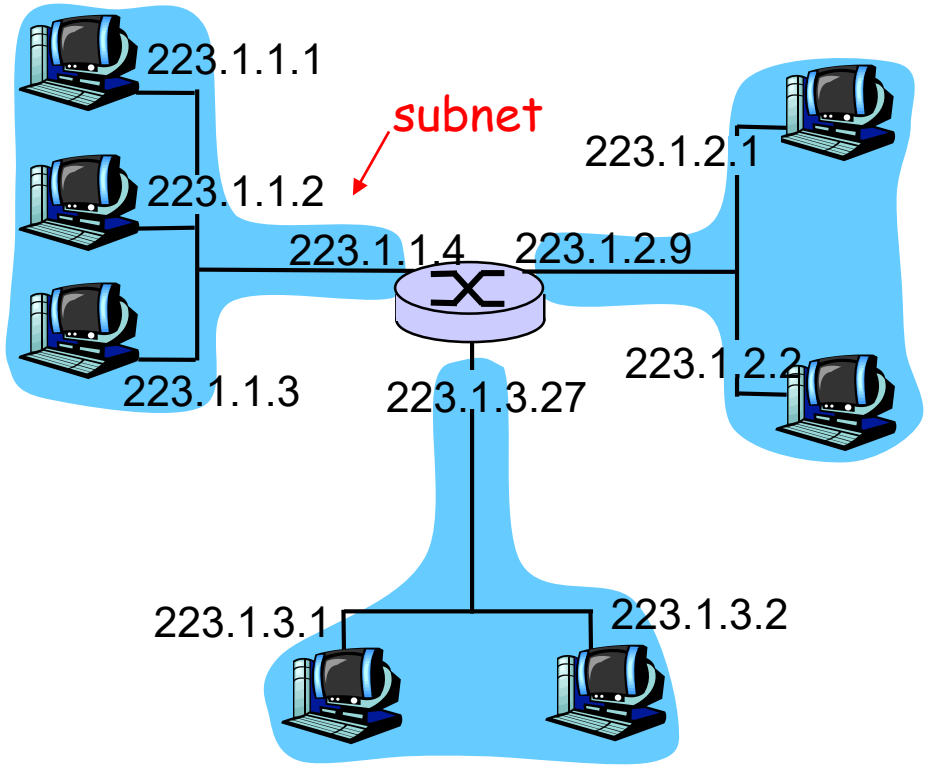
network consisting of 3 subnets

- *Subnet mask is 255.255.255.0.*

IP address	Network address	Host address
223.1.3.1	233.1.3.0	0.0.0.1
223.1.3.26	233.1.3.0	0.0.0.26
223.1.3.2	233.1.3.0	0.0.0.2

Subnets

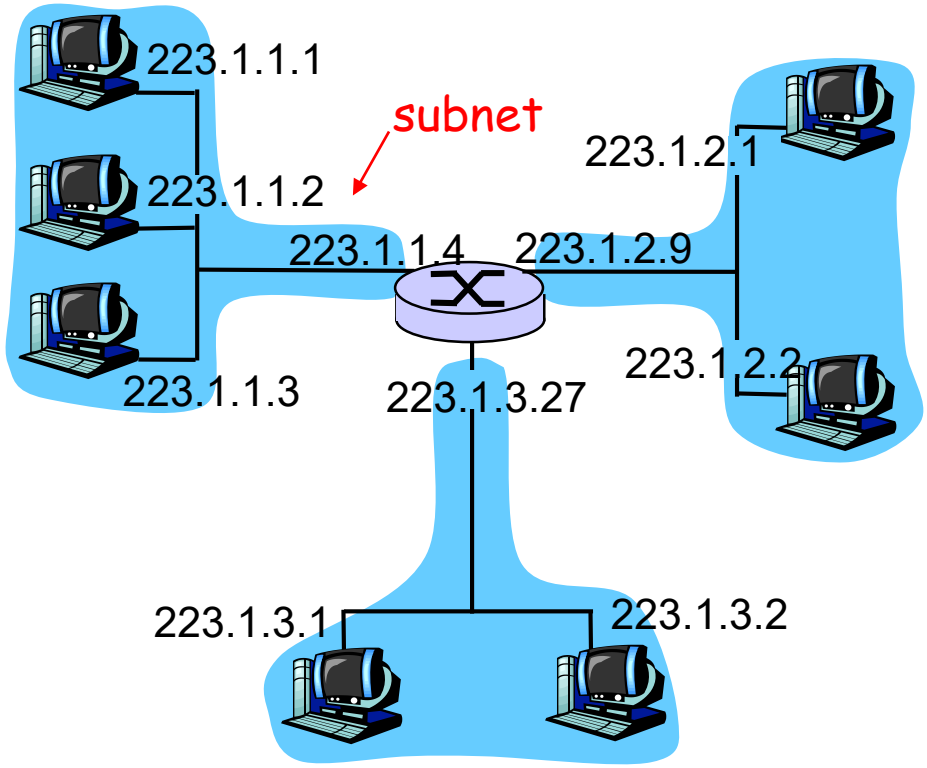
- *IP address of subnet*
  - Network address: When the host part of the IP address is set to all 0s, it is used to identify the network address of a subnet.
  - For example, the subnet mask of the left subnet is 255.255.255.0; and its network address is 223.1.1.0
  - Broadcast address: When the host part of the IP address is set to all 1s, this packet is sent to all nodes in this subnet.



network consisting of 3 subnets

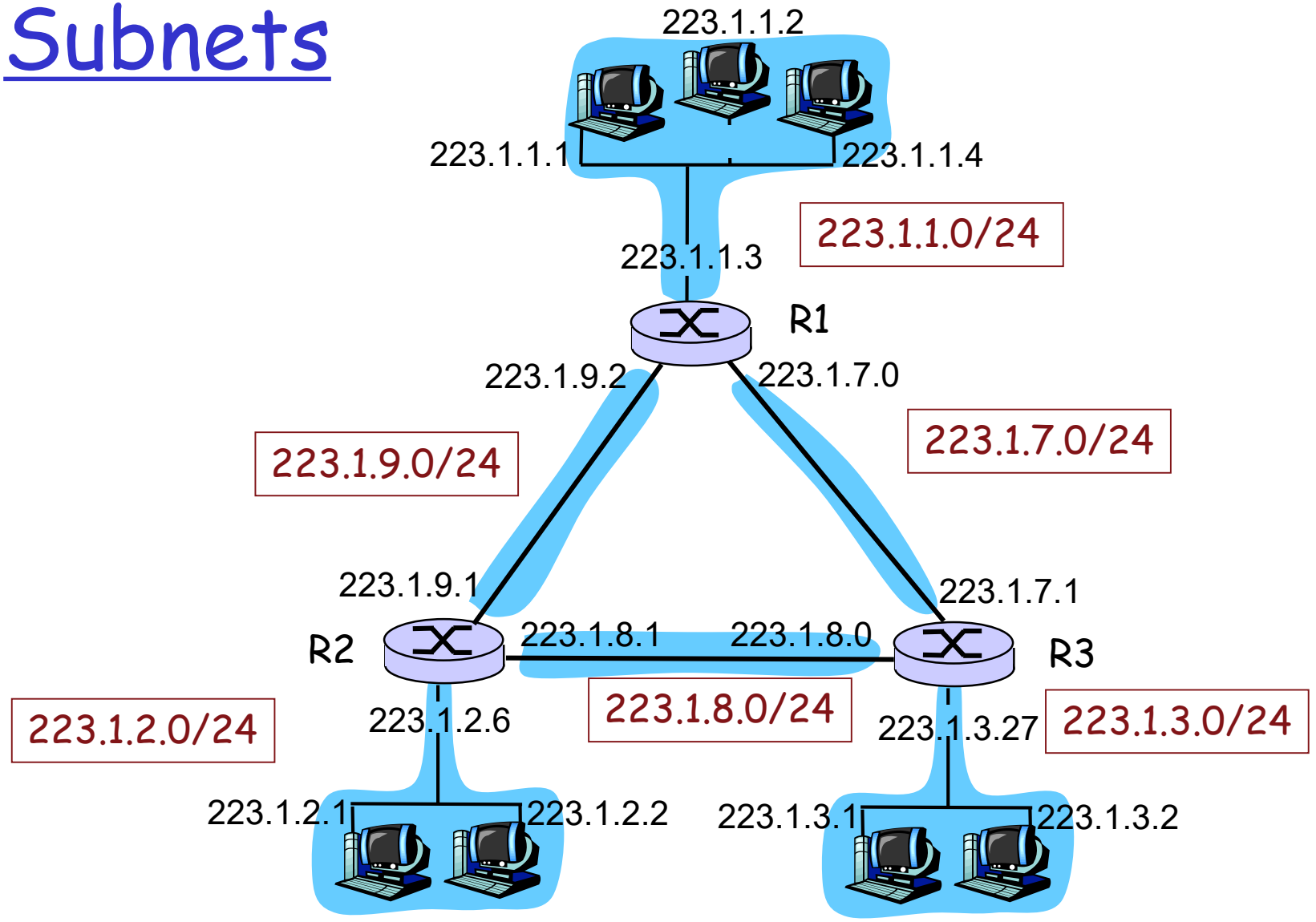
Subnets

- *IP address of subnet*
  - For example, a subnet address is 223.1.1.0 with network mask /24. Then, the packet with the destination address 223.1.1.255 will be send to all nodes in this subnet.

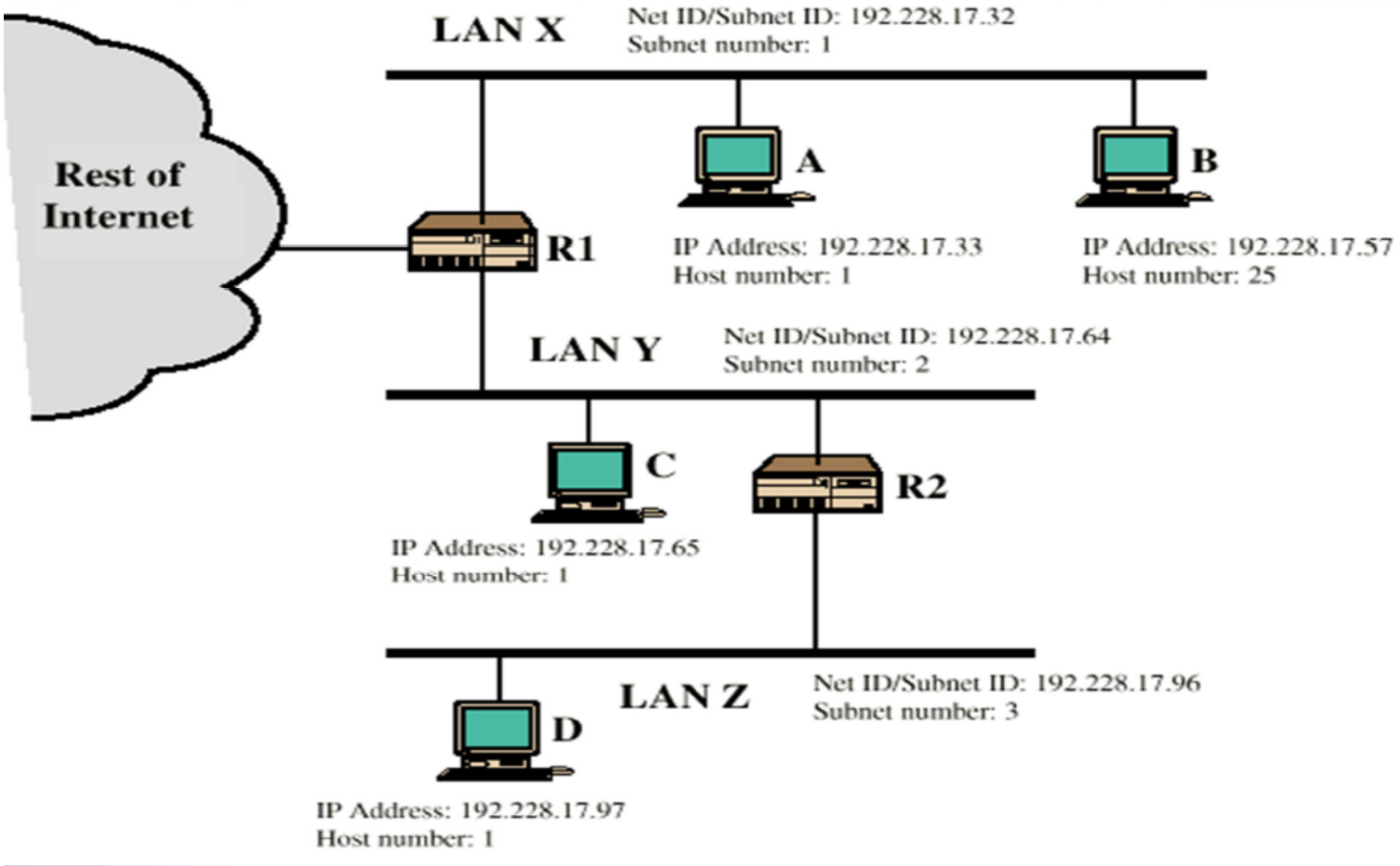


network consisting of 3 subnets

Subnets

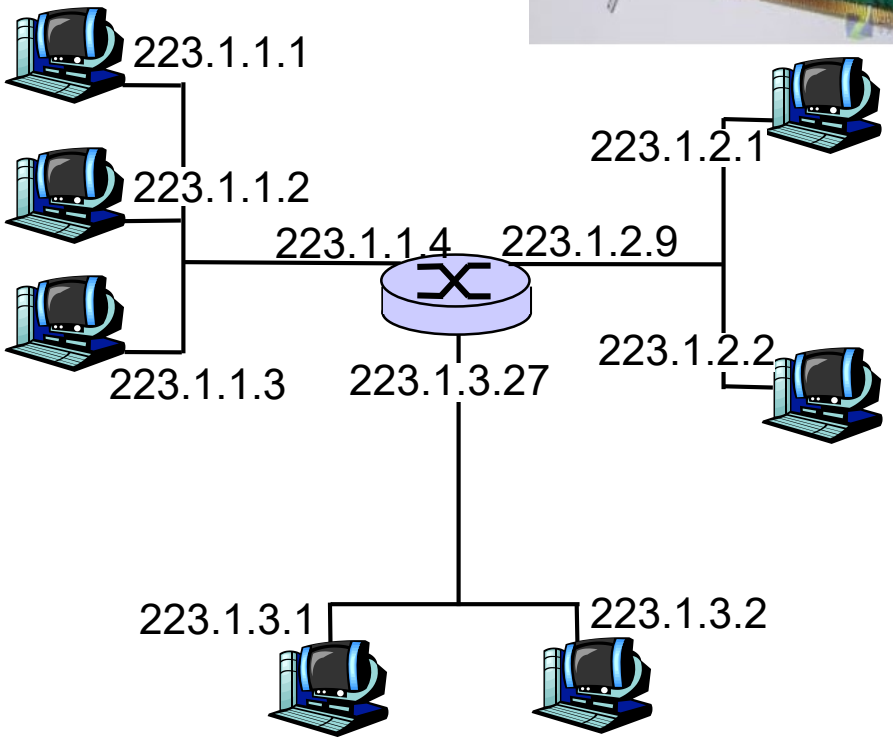

223.1.1.2
223.1.1.1
223.1.1.4
223.1.1.0/24
223.1.1.3
R1
223.1.9.2
223.1.7.0
223.1.9.0/24
223.1.7.0/24
223.1.9.1
223.1.7.1
R2
223.1.8.1
223.1.8.0
R3
223.1.2.0/24
223.1.2.6
223.1.8.0/24
223.1.3.27
223.1.3.0/24
223.1.2.1
223.1.2.2
223.1.3.1
223.1.3.2

Subnets


LAN X
Net ID/Subnet ID: 192.228.17.32
Subnet number: 1
Rest of Internet
A
B
R1
IP Address: 192.228.17.33
Host number: 1
IP Address: 192.228.17.57
Host number: 25
LAN Y
Net ID/Subnet ID: 192.228.17.64
Subnet number: 2
C
R2
IP Address: 192.228.17.65
Host number: 1
LAN Z
Net ID/Subnet ID: 192.228.17.96
Subnet number: 3
D
IP Address: 192.228.17.97
Host number: 1

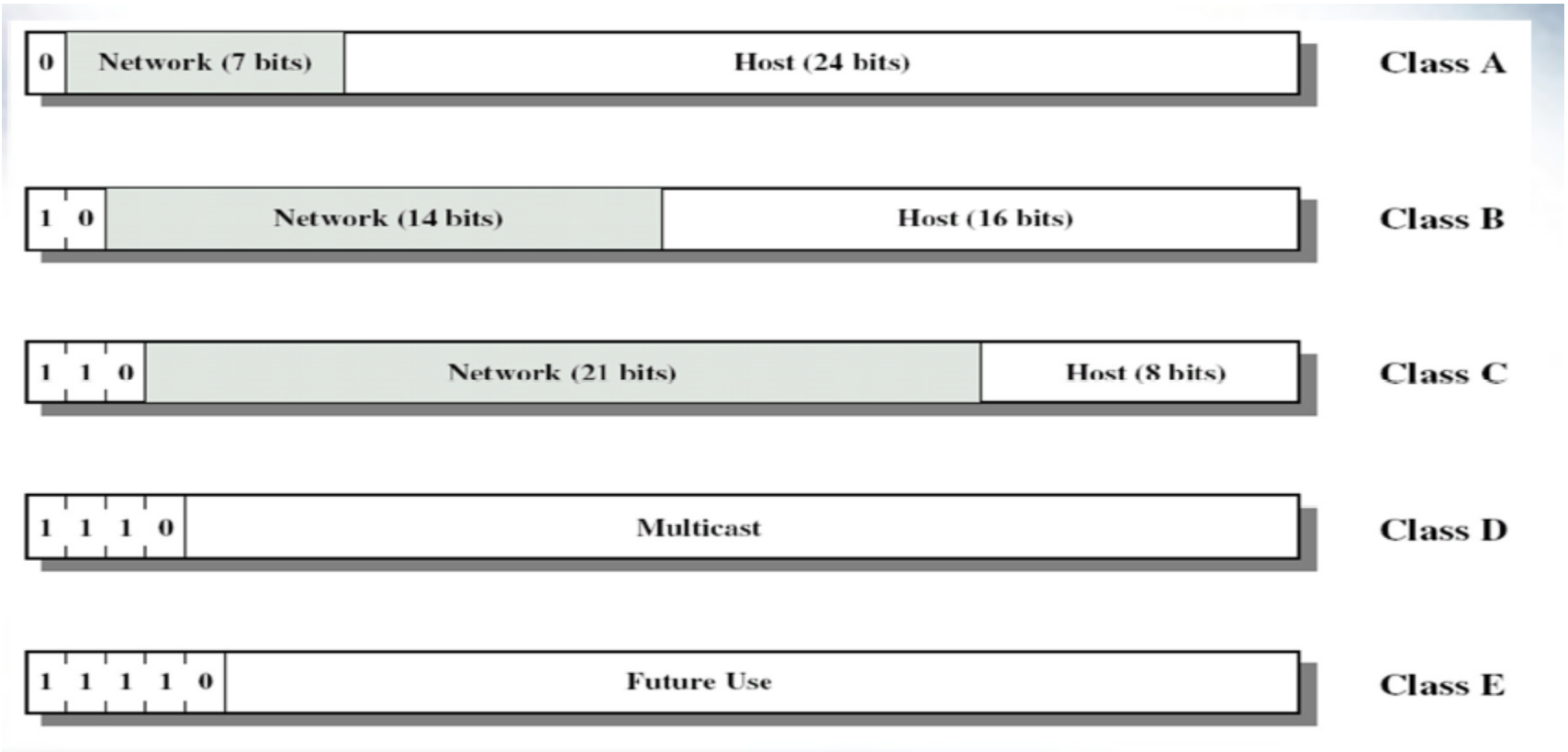
Two IP Addressing Schemes

- *Classful addressing:*
  - Address space is divided into 5 classes: A, B, C, D, and E
- *Classless addressing*
  - Each interface on every host and router in the Internet must have a globally unique IP address.



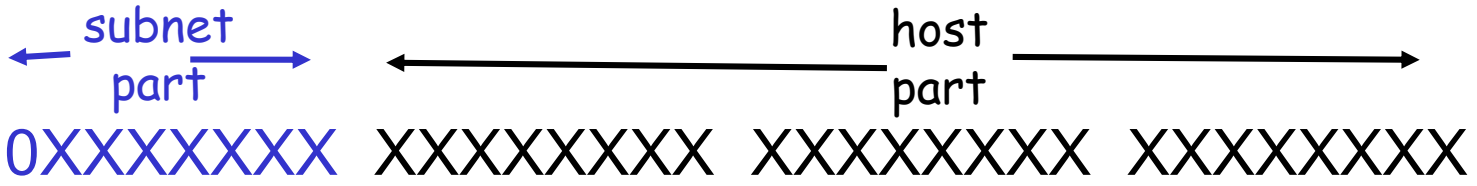
Classful IP Addressing Scheme

- Before CIDR (Classless Interdomain Routing) was adopted, the network portions of an IP address were constrained to be 8, 16, or 24 bits in length. This addressing scheme is known as classful addressing.



5 IP Address Classes

- Class A IP address: Few networks, each with many hosts

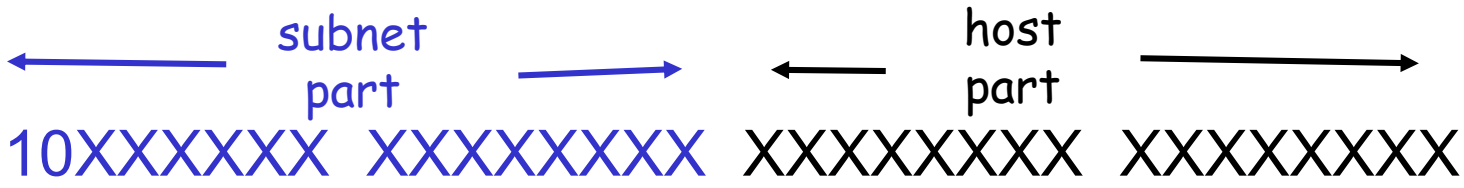


For example, 120.52.26.72/8

- Start with binary 0
- Range 0.0.0.0 to 127.255.255.255
- 2^7= 128 class A addresses
- 00000000 and 01111111 (127) are reserved
- 126 class A networks are in use。
- All allocated

5 IP Address Classes

- Class B IP address: Medium number of networks, each with a medium number of hosts

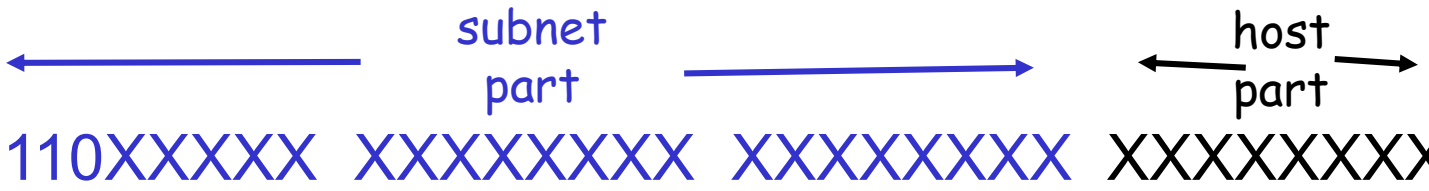


For example, 191.52.26.72/16

- Start with 10
- Range 128.0.0.0 to 191.255.255.255
- Second byte is also included in network address
- 2^{14}= 16,384 class B addresses
- Example: 162.105.131.113
- All allocated

5 IP Address Classes

- Class C IP address: Many networks, each with a few hosts.



For example, 192.52.26.72/24

- Start with 1 1 0
- Range 192.0.0.0 to 223.255.255.255
- Second and third bytes are part of network address
- 2^{21}=2,029,152 network addresses
- Nearly all allocated

5 IP Address Classes

- Class D IP address: Used for multicast.

1110XXXX XXXXXXXX XXXXXXXX XXXXXXXX

For example, 230.52.26.72

  - Start with 1 1 1 0
  - Range 224.0.0.0 to 239.255.255.255

5 IP Address Classes

- Class E IP address: beginning with 1111XXXX or from 240 to 255 of first byte in decimal.

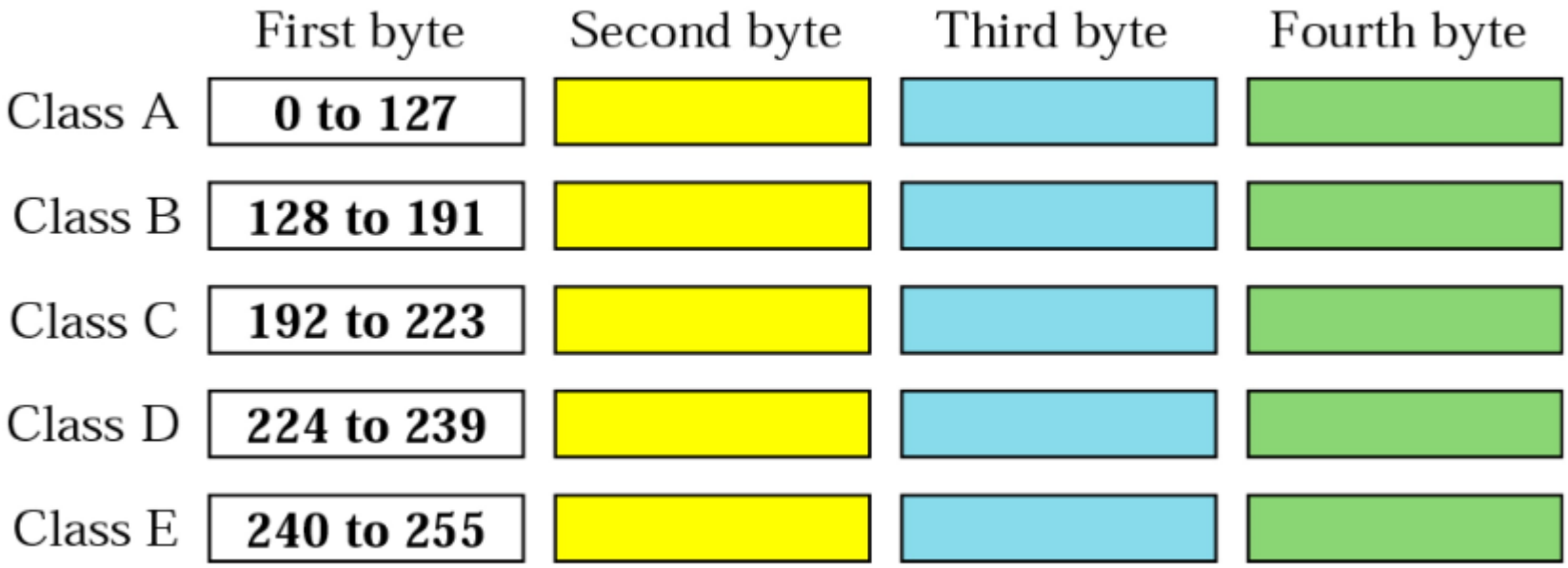
- Class E addresses are reserved, but not used in Internet untill now.

1111XXXX XXXXXXXX XXXXXXXX XXXXXXXX

For example, 250.52.26.72

Classful IP Addressing Scheme

- Addresses in class A, B, C are for unicast communication; Addresses in class D are for multicast communication; addresses in class E are reserved.



Classless IP Address Format

- CIDR: The Internet's address assignment strategy is known as Classless Interdomain Routing (CIDR)
- 32 bit global Internet IP address: support about 640 million addresses
- IP address format: network part and host part, dotted-decimal notation a.b.c.d/x, where x is the number of bits in subnet portion of address

200.23.16.0/23

/x indicates that x left most bits of the 32-bit IP address is the subnet part, and remaining (32-x) bits is the host part

Classless IP Address Format

- Advantages
  - Provide high flexibility
  - Provide high scalability

- Some specific addresses
  - When the host part of an address is set to all 1s, it is a broadcast address, specifying that it is sent to all nodes in this subnet.
  - When the host part of an address is set to all 0s, it is used to indicate this subnet.
  - Addresses beginning with 127 are reserved for internal testing on the local machine.

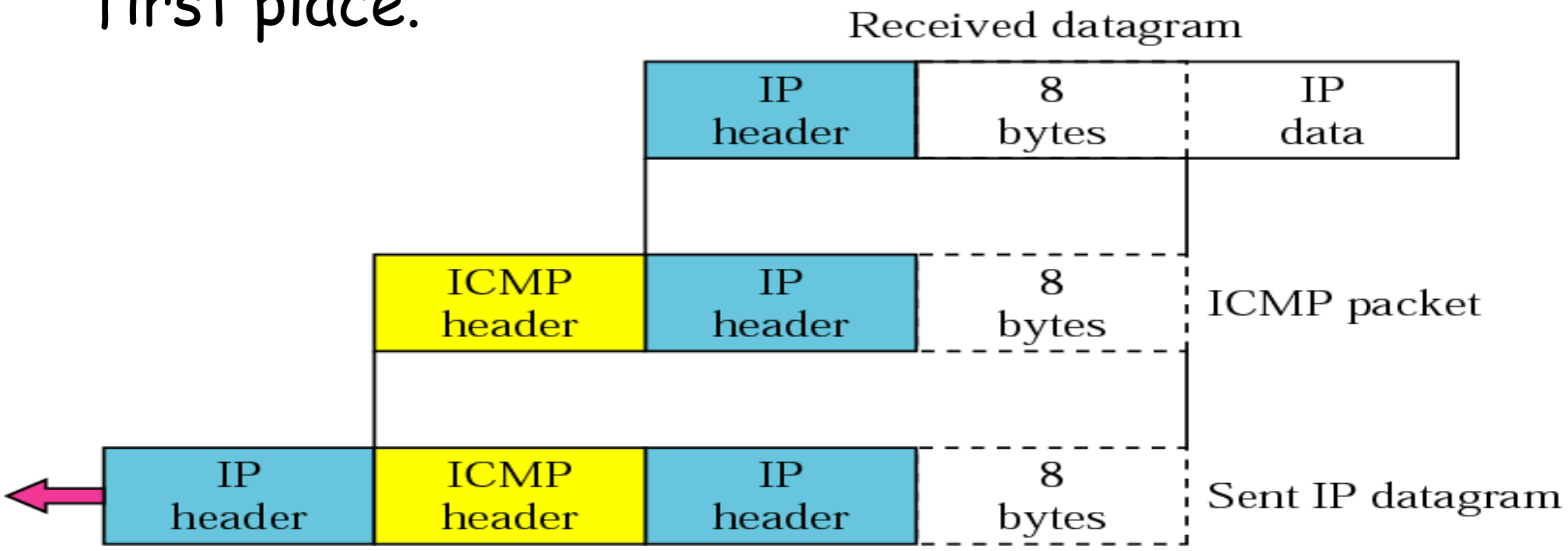
ICMP: Internet Control Message Protocol

ICMP: Internet Control Message Protocol

- It is used by hosts or routers to communicate network-layer information
  - It generates error reporting messages: unreachable host, network, port, protocol
  - Echo request/reply (i.e., ping)
- Function of ICMP
  - A node recognizing a transmission problem (TTL exceed, destination unreachable, etc.) generates ICMP messages
  - ICMP provides some useful diagnostics about network operation (ping, tracert)

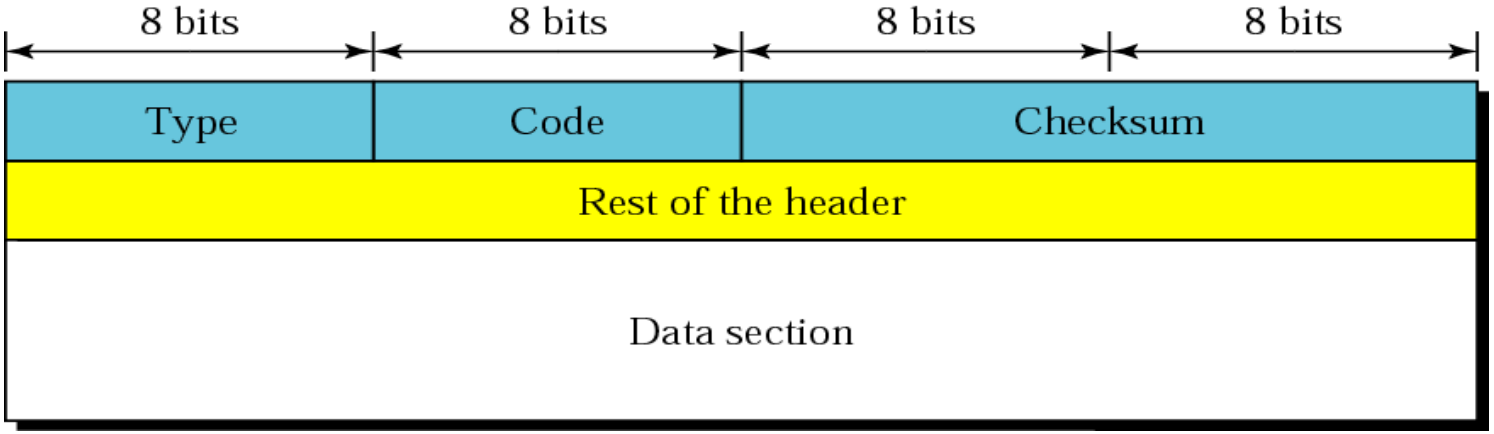
ICMP Message Encapsulation

- Architecturally, ICMP is just above IP
- ICMP message is encapsulated in IP datagram. That is, ICMP message is carried as IP payload
- ICMP message/packet includes
  - ICMP header (type, code field)
  - The header and the first 8 bytes of the IP datagram that caused the ICMP message to be generated in the first place.



ICMP Message Format

- Header
  - Type: relevant ICMP message
  - Code: more details information
  - Checksum: covers ICMP header/data

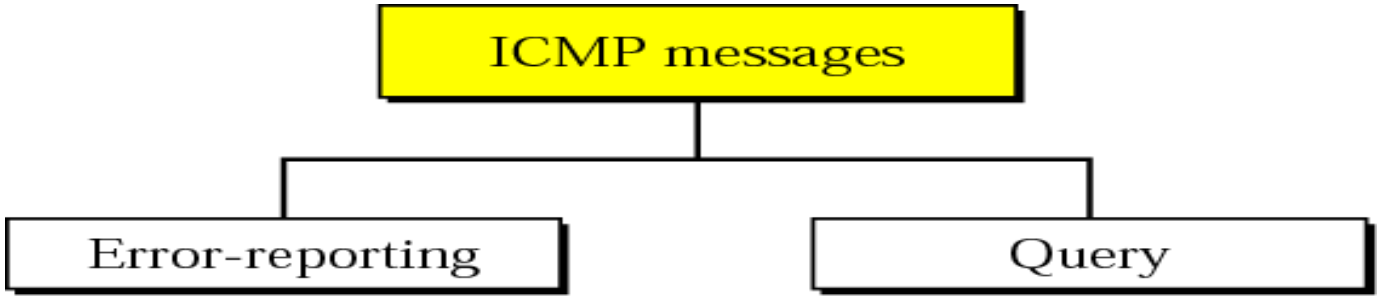


ICMP header

Type	Code	Meaning
0	0	echo reply
3	0	network unreachable
3	1	host is unreachable
3	3	port is unreachable

ICMP Types

- ICMP messages are divided into error-reporting messages and query messages.
- The error-reporting messages report problems that a router or a host (destination) may encounter.
- The query messages get specific information from a router or another host.



ICMP Types

- ICMP

Type	Code	Meaning	
			(Query)
			(Error-reporting)
4	0	source quench	
5	0	redirect	
			(Query)
9/10	0	router discovery/advertisement	
			(Error-reporting)
12	0	parameter problem	
13/14	0	time stamp request	
17/18	0	network request/reply	

Ping Command

- Send an ICMP type 8 code 0 message to the specific host
- Ping can be used to
  - Get timing information
  - Detect connection reliability
  - Check if destination is unreachable (routable)

```
C:\Users\MPI>ping www.ust.hk

Pinging www.ust.hk [143.89.14.34] with 32 bytes of data:
Reply from 143.89.14.34: bytes=32 time=25ms TTL=244
Reply from 143.89.14.34: bytes=32 time=13ms TTL=244
Reply from 143.89.14.34: bytes=32 time=14ms TTL=244
Reply from 143.89.14.34: bytes=32 time=33ms TTL=244

Ping statistics for 143.89.14.34:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 13ms, Maximum = 33ms, Average = 21ms

C:\Users\MPI>_
```

Ping Command

- How does ping work?
  - Send ICMP type 8 code 0 messages (echo request) and wait for a reply.
  - If the reply is not received within one second, send another request, continue until at least one reply is received or stop after timeout.
  - Record the round-trip time
    - Record the time it takes for each reply and calculate the round-trip timing since each echo request contains a unique sequence number to match reply.
  - Do packet lost statistics

```
C:\Users\MPI>ping www.ust.hk

Pinging www.ust.hk [143.89.14.34] with 32 bytes of data:
Reply from 143.89.14.34: bytes=32 time=25ms TTL=244
Reply from 143.89.14.34: bytes=32 time=13ms TTL=244
Reply from 143.89.14.34: bytes=32 time=14ms TTL=244
Reply from 143.89.14.34: bytes=32 time=33ms TTL=244

Ping statistics for 143.89.14.34:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
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