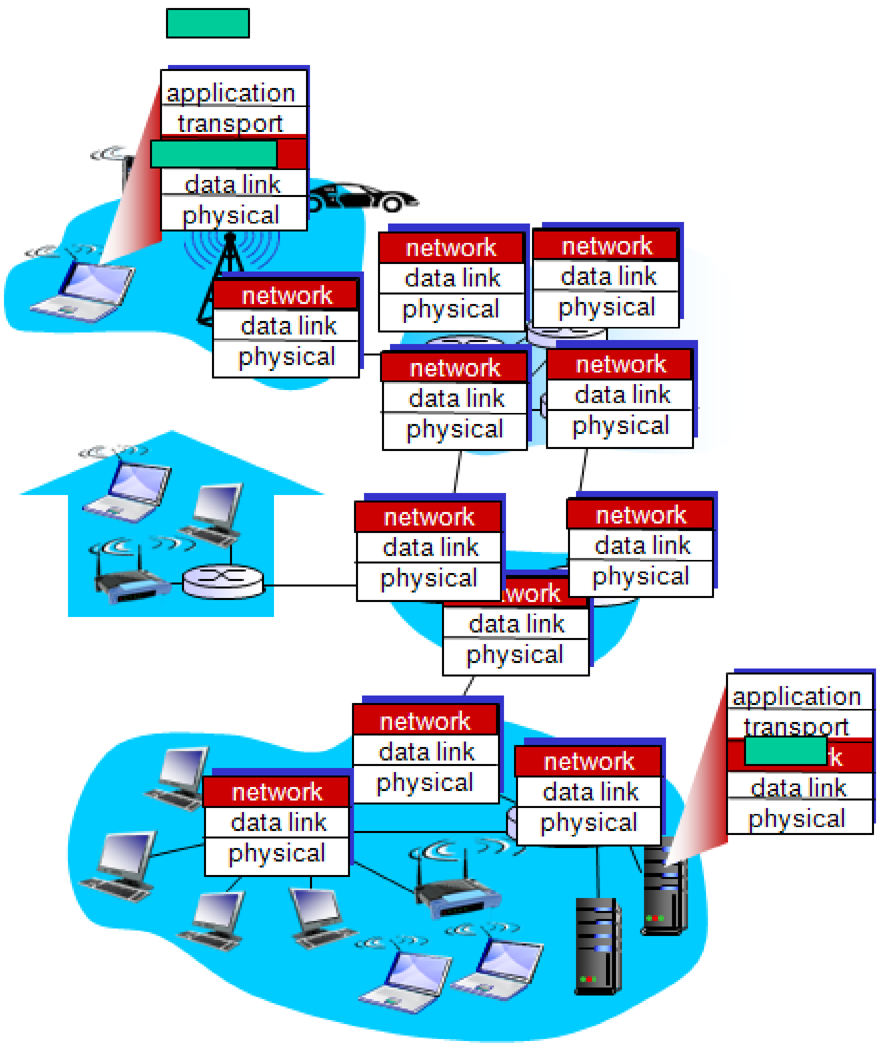
Internet Protocol (IP)
“The” Network Layer

EE450: Introduction to Computer Networks

Professor A. Zahid

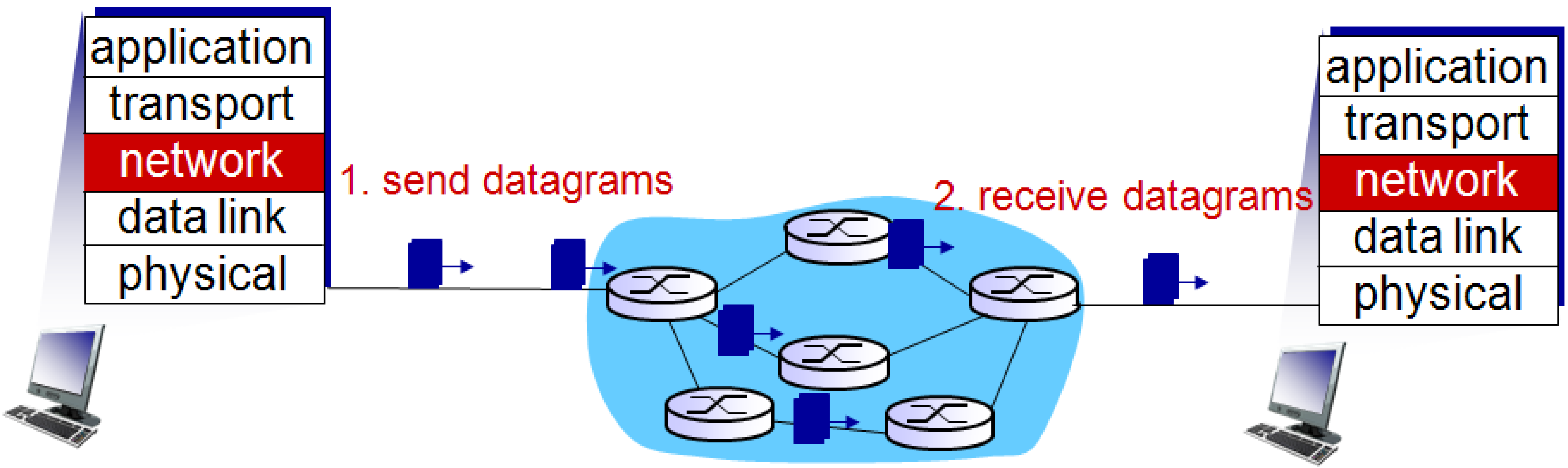
Network Layer

- On sending side, it encapsulates TCP Segments (or UDP Datagrams) into **Packets**
- On receiving side, it delivers TCP Segments (or UDP Datagrams) to corresponding Transport layer
- Network layer protocols are implemented in **every** host and router across the Network
- Router examines header fields in all IP packets passing through it and forward according to routing tables

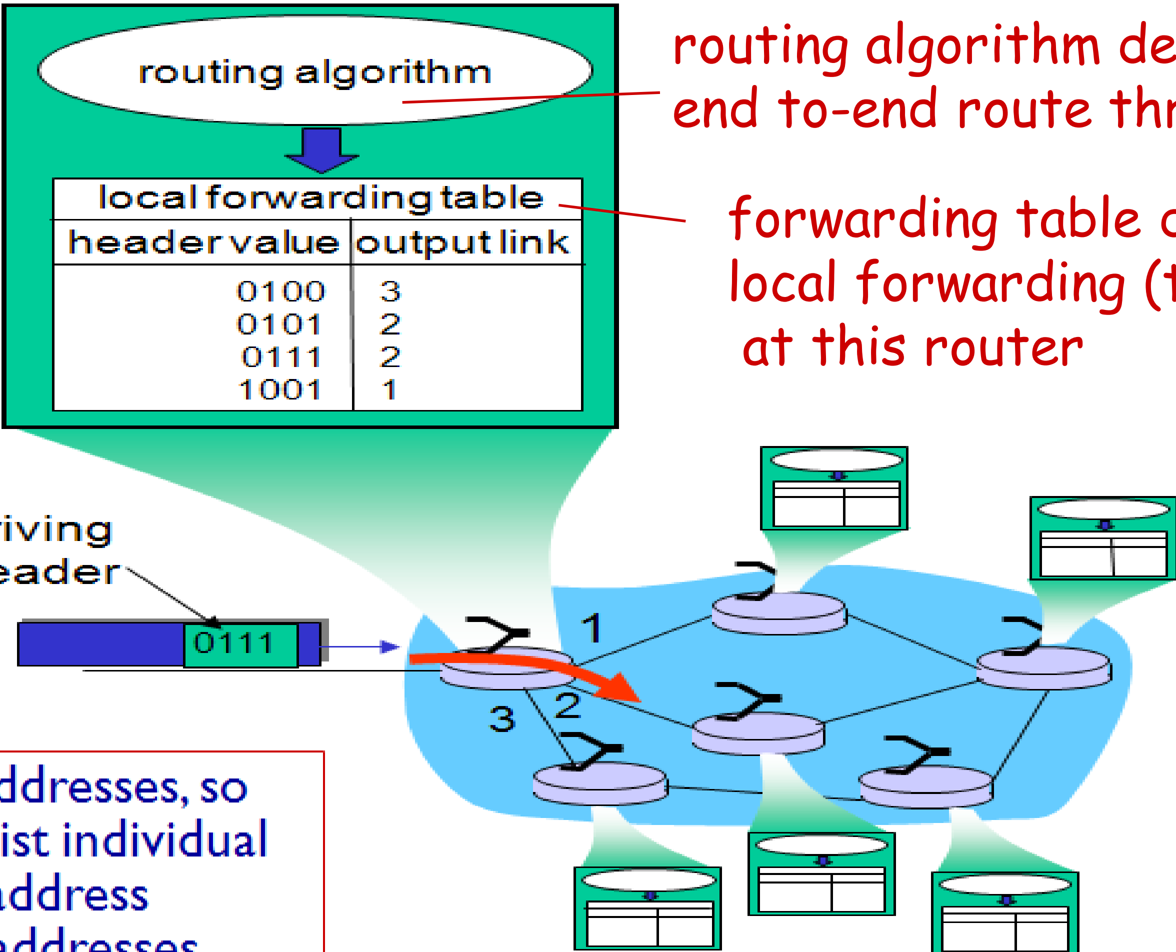


Packet Switched Network (Review)

- No call setup at Network layer
- Routers: no state about end-to-end connections
  - Packets may arrive out-of-order
- Packets forwarded using destination IP address



Routing vs. Forwarding



routing algorithm determines end to-end route through network

forwarding table determines local forwarding (to next hop) at this router

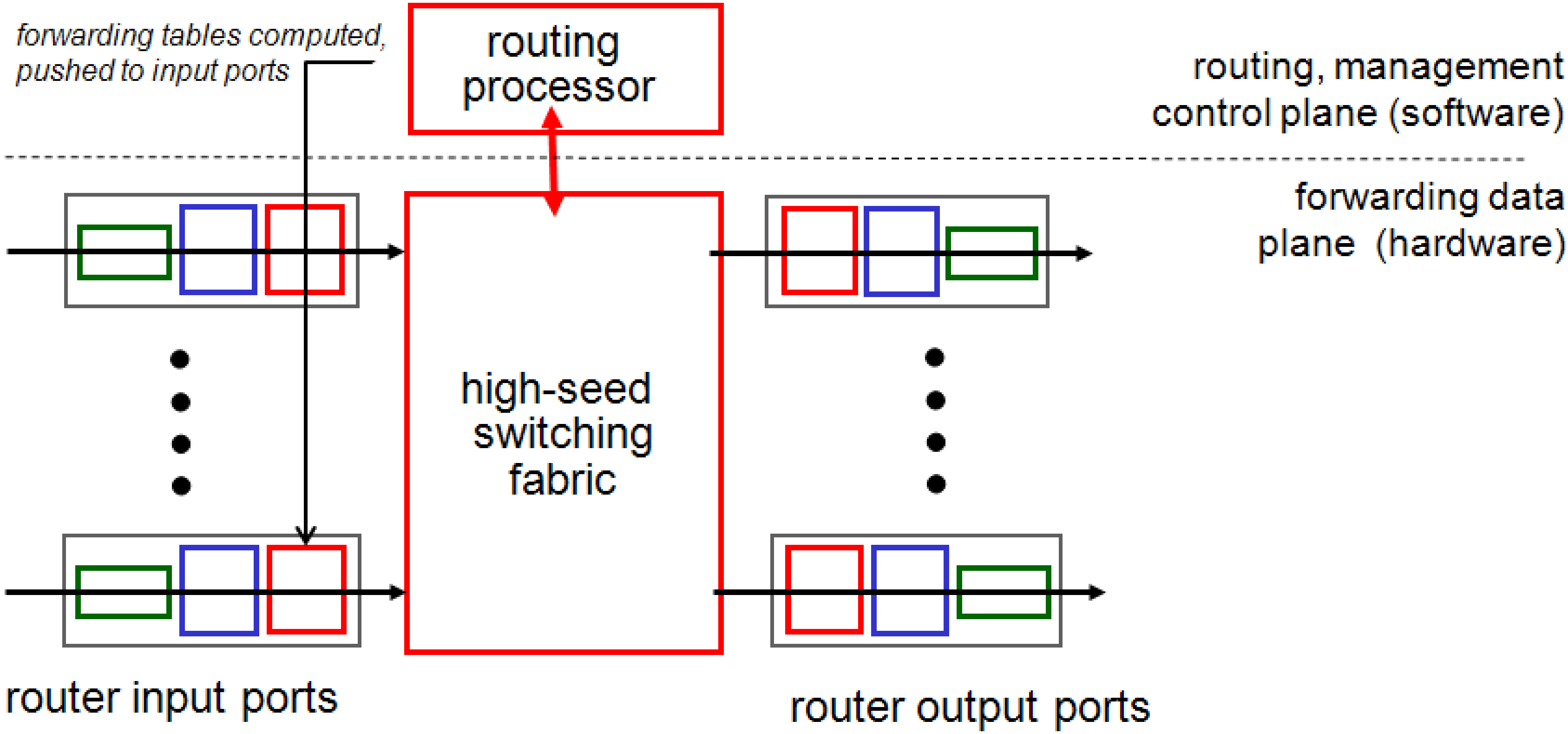
value in arriving packet's header

4 billion IP addresses, so rather than list individual destination address list *range* of addresses (aggregate table entries)

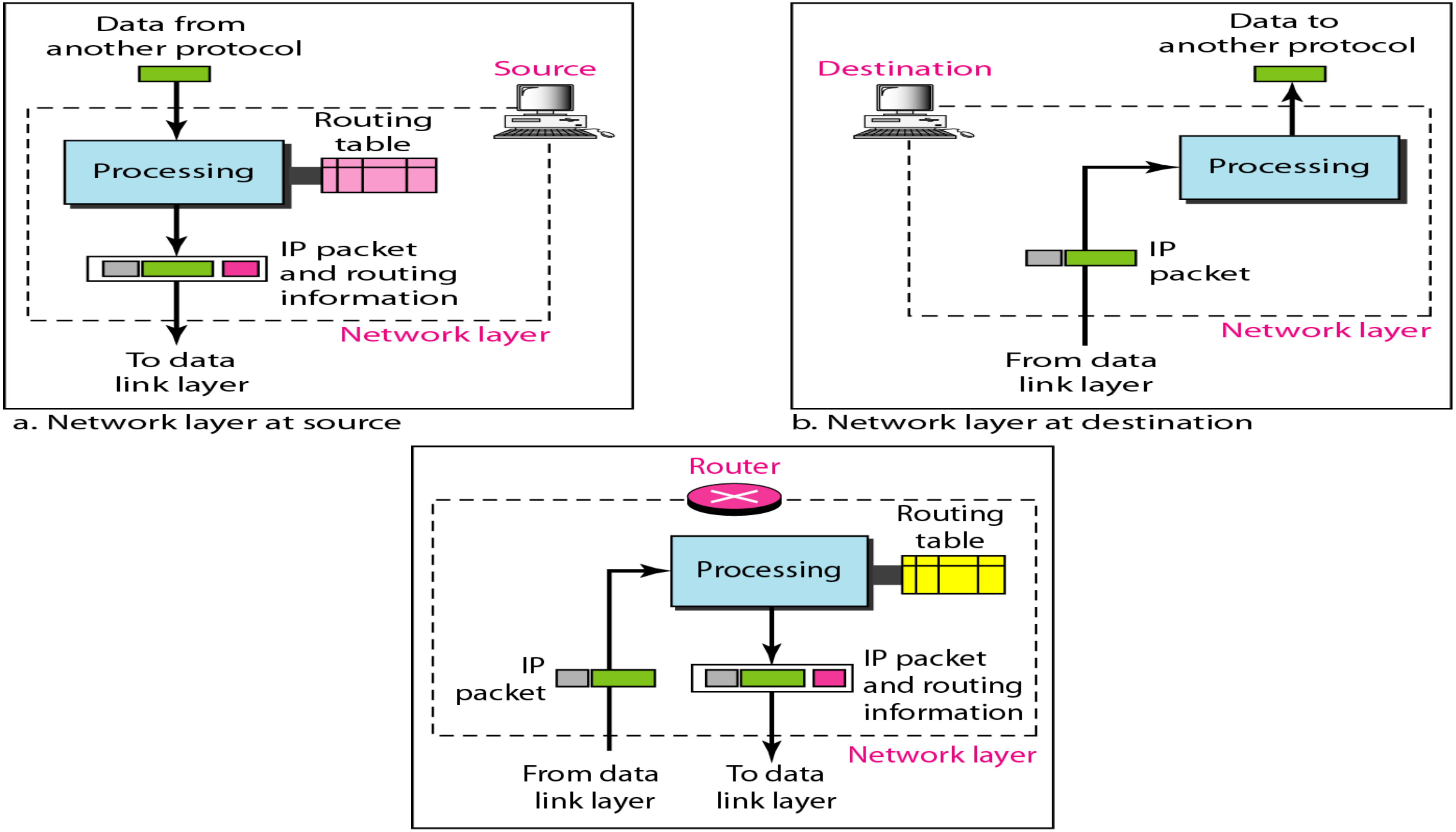
Router Architecture (EE555)

two key router functions:

- Run Routing algorithms/protocols (RIP, OSPF, BGP)
- forwarding packets from incoming to outgoing link



Network Layer at Source/Router/Destination

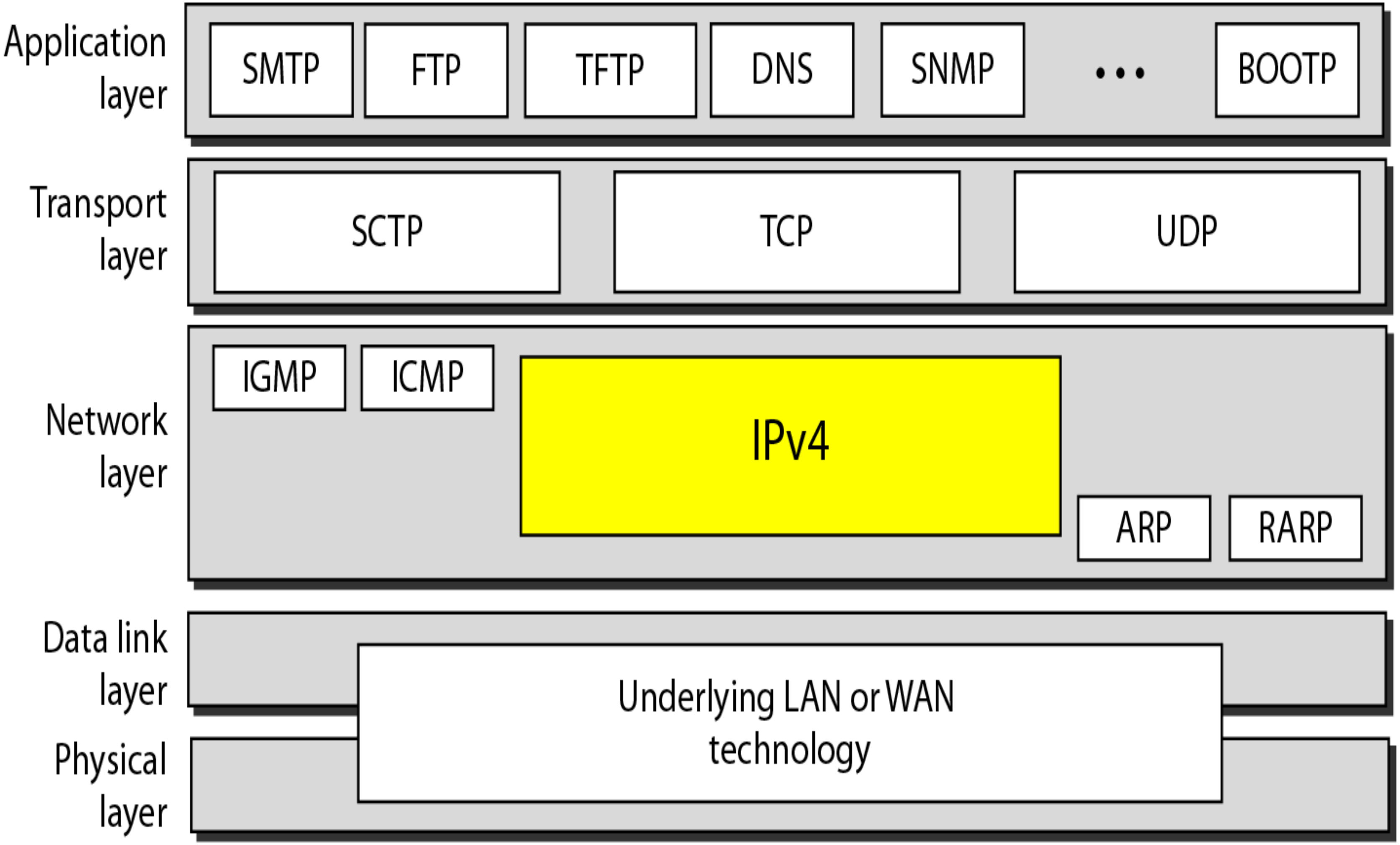


a. Network layer at source

b. Network layer at destination

c. Network layer at a router

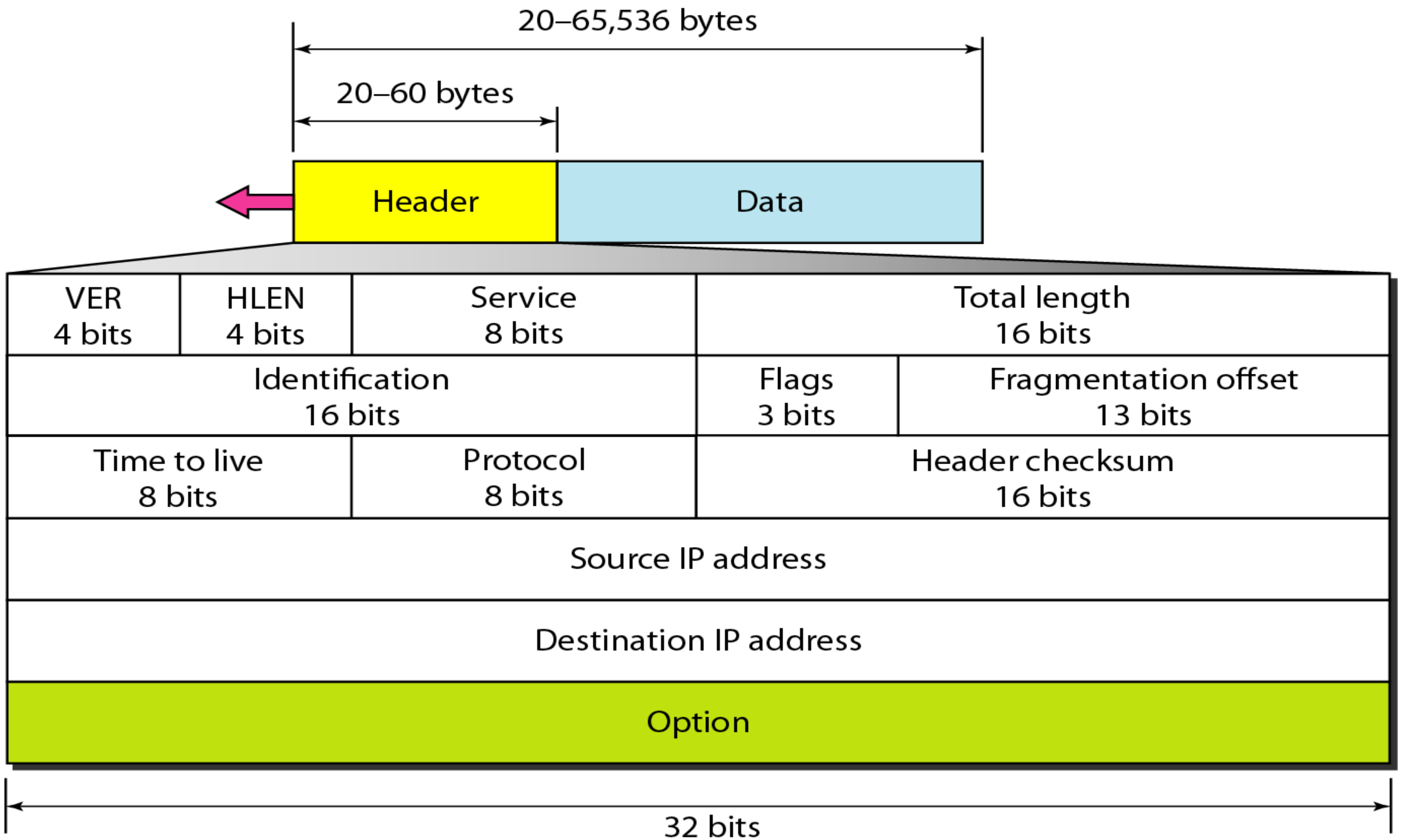
The IP Protocol



The Internet Protocol

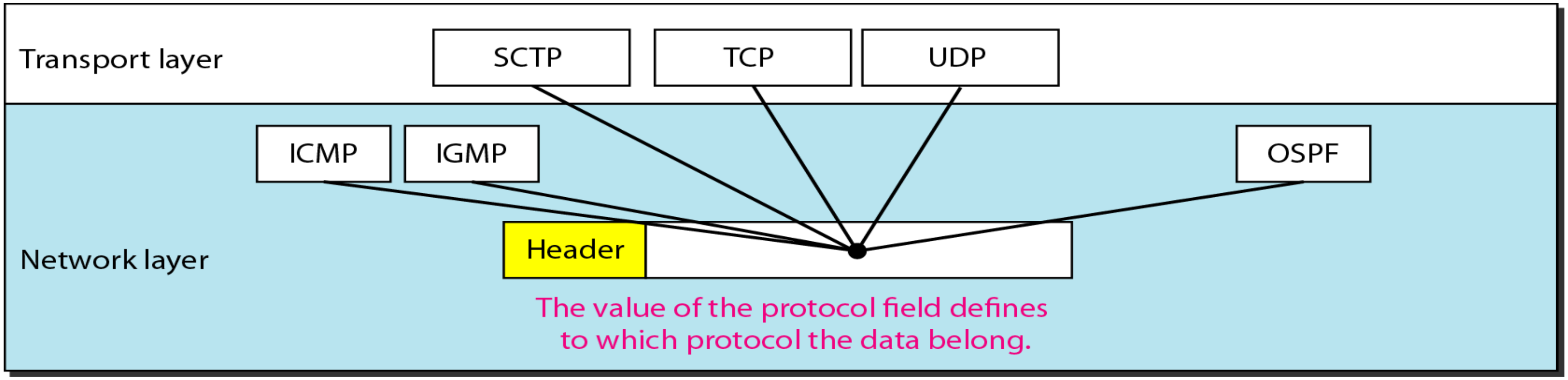
- IP is a connection-less, unreliable network layer protocol designed to be used in a connection-less packet switched network such as the Internet.
- IP provides best effort services in the sense
  - There is no guarantee of delivery of error-free packets
  - There is no guarantee of ordered delivery of packets
  - There is no guarantee of delivery of packets, i.e. some packets may be lost, some packets may be duplicated
- IP relies on upper layer transport protocols (TCP) to take care of these problems

IP Packet Format



The Protocol Field

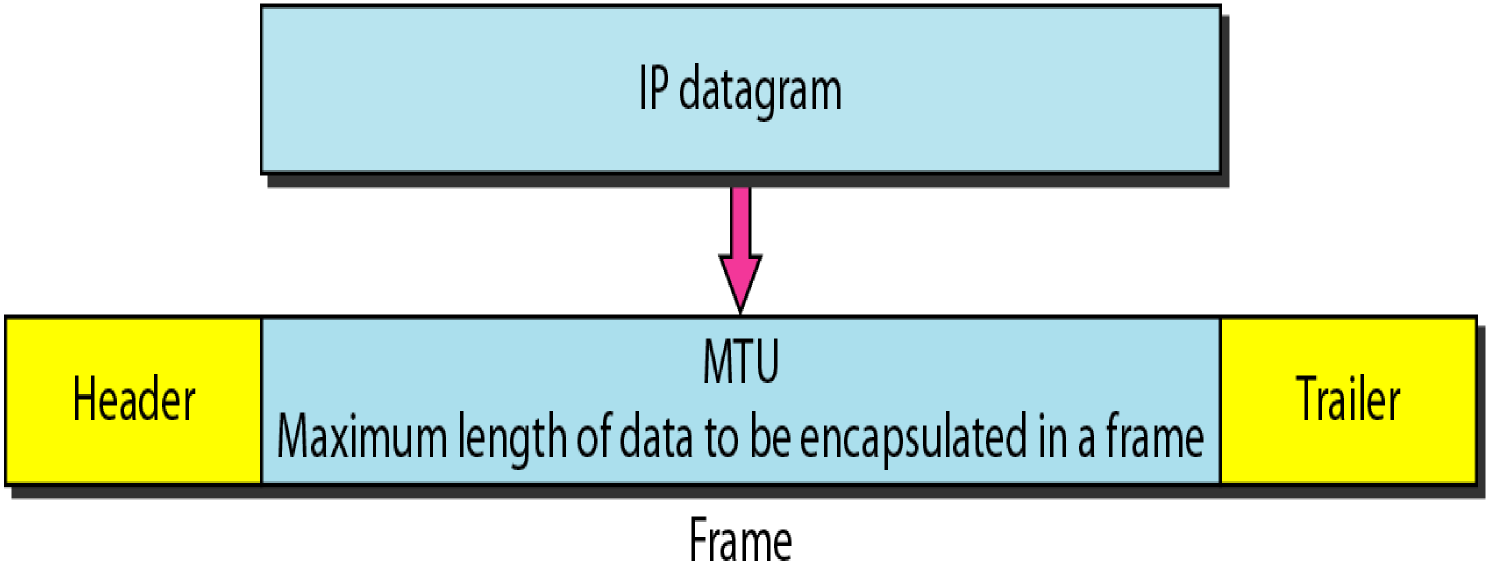
- The protocol field (8-bits) defines the protocol that is using the services of IP. It defines the final destination protocol the packet should be delivered to. This is important since several protocols could be multiplexed over IP
  - ICMP : 1, IGMP: 2, TCP: 6, EGP: 8, UDP: 17, IPv6: 41, OSPF: 89, etc...



Fragmentation

- IP packet may travel over different networks (LANs and WANs)
- A router de-capsulate an IP packet from the frame it receives, process it, and encapsulate it in another frame
- Frame size and format varies depend on the data link protocol used by the physical network through which the frame is traveling
- MTU (Maximum Transmission Unit) is the maximum size of the data field (payload) in the frame
- If Packet size > MTU, Need for Fragmentation

MTU: Maximum Transfer Unit



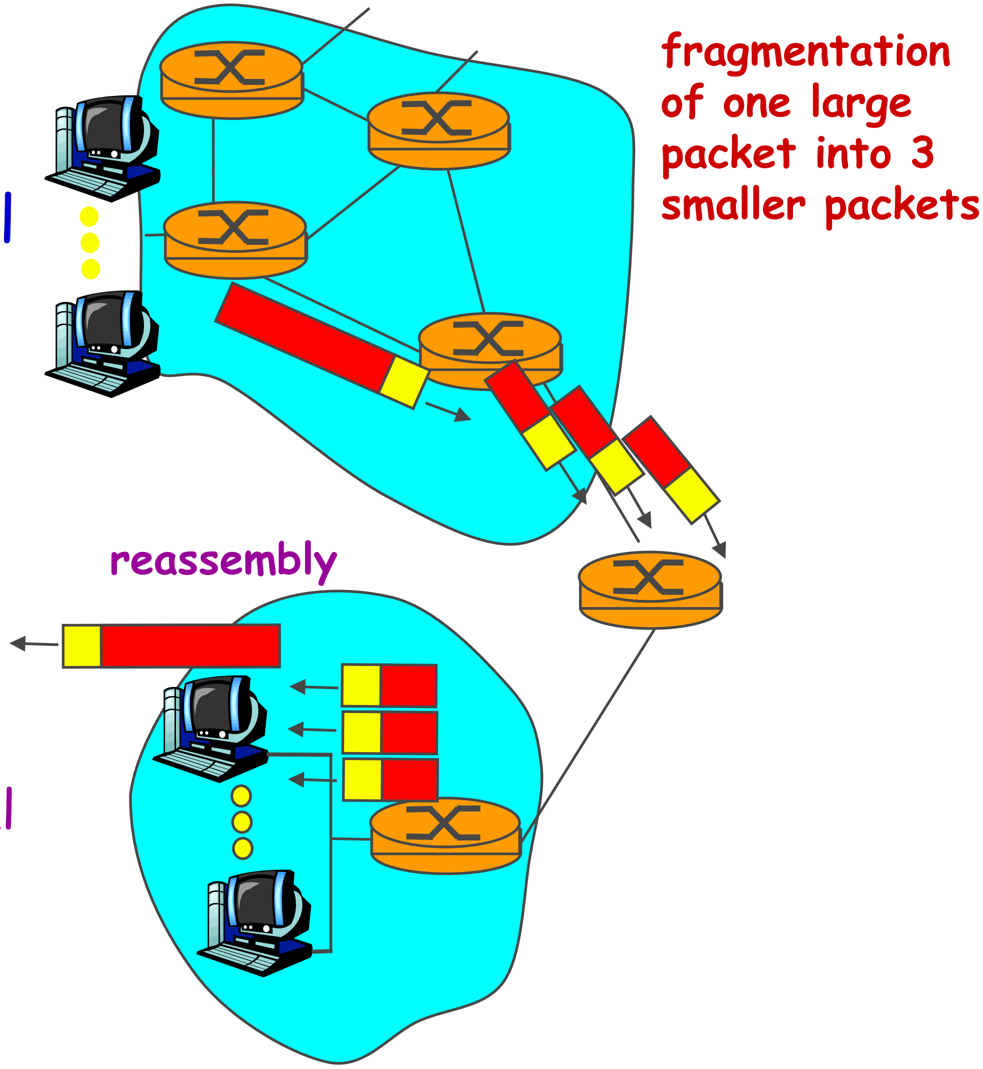
Protocol	MTU (Octets)
Ethernet	1500
Token Ring (4 Mbps)	4464
Token Ring (16 Mbps)	17914
FDDI	4352
X.25	576
PPP	296

Fragmentation (Continued)

- Each fragment has its own header (most of fields are copied, some will change, including the total length, the Flags and the fragmentation offset fields)
- A fragmented datagram may itself be fragmented if it encounters a network with smaller MTU
- A packet can be fragmented by a source host or by any router in the path. Re-assembly of the packet must be done at the destination host because those fragments become independent packets and may travel different routes

Fragmentation and Reassembly

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



Fields related to Fragmentation

- Identification (16 bits): All fragments of a packet has the same ID number which is the same as that of the original packet. The R/x knows that all fragments having the same ID should be assembled into one packet

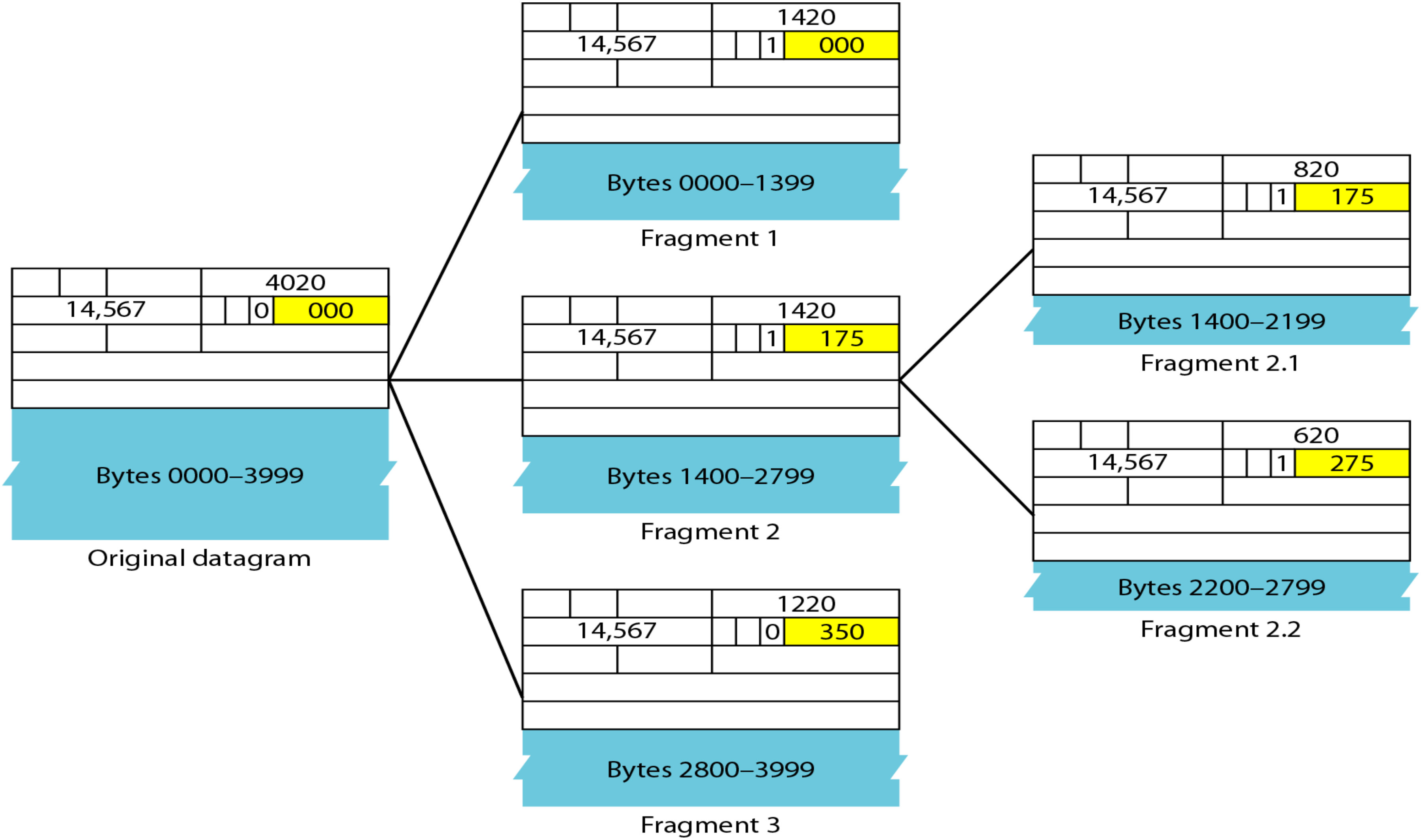
- Flags (3 bits):

	D	M

D: Do not Fragment
M: More Fragment

- Fragmentation Offset (13 bits): Relative position of the fragment to the whole packet measured in units of 8 Bytes

Fragmentation Example (cont.)



IP v4. Addressing

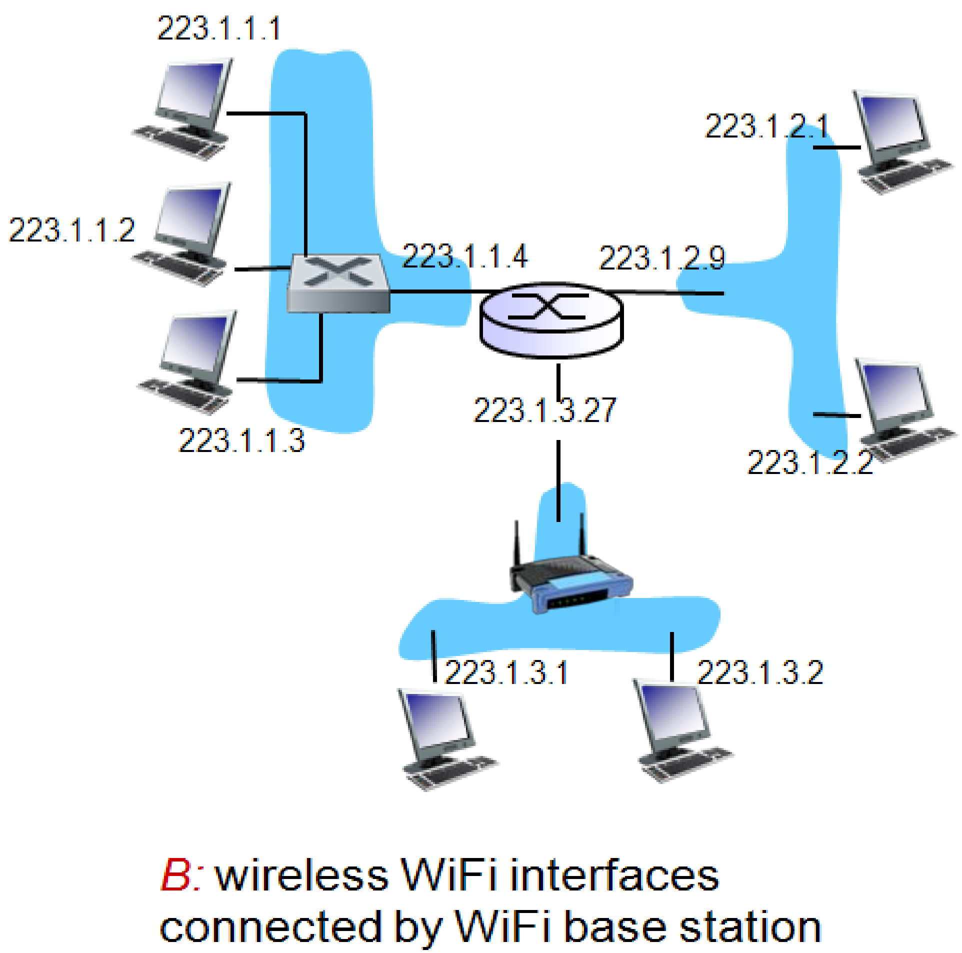
- The Internet is made of combination of LANs and WANs connected via routers
- A host needs to be able to communicate with another host without worrying about which physical network must be passed through
- Hosts must therefore be identified uniquely and globally at the network layer
- For efficient and optimum routing, routers must also be identified uniquely and globally at the network layer

IP v4. Addressing (Cont.)

- IPv4 address is a 32-bit address, implemented in software, is used to uniquely and globally identify a host or a router on the Internet
- A device can have more than one IP address if it is connected to more than one network (multi-homed)
- An IP address have two parts, the netid and the hostid. They have variable lengths depending on the class of the address
- All devices on the same network have the same netid

IP Addresses (Example)

- 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



Classful IP Addressing

	First byte	Second byte	Third byte	Fourth byte
Class A	0			
Class B	10			
Class C	110			
Class D	1110			
Class E	1111			

a. Binary notation

	First byte	Second byte	Third byte	Fourth byte
Class A	0–127			
Class B	128–191			
Class C	192–223			
Class D	224–239			
Class E	240–255			

b. Dotted-decimal notation

Number of Blocks/Size of Blocks in Classful IP Addressing

Class	*Number of Blocks*	*Block Size*	*Application*
A	128	16,777,216	Unicast
B	16,384	65,536	Unicast
C	2,097,152	256	Unicast
D	1	268,435,456	Multicast
E	1	268,435,456	Reserved

In classful addressing, a large part of the available addresses are wasted. It is hence being replaced by "Classless IP Addressing"

Special IP Addresses

Special Address	Netid	Hostid	Source/Destination
▪ Network Address	Specific	All 0's	None
▪ Direct Broadcast Address	Specific	All 1's	Destination
▪ Limited Broadcast Address	All 1's	All 1's	Destination
▪ This host on this network	All 0's	All 0's	Source
▪ Specific host on this network	All 0's	Specific	Destination
▪ Loopback address	127	Any	Destination

Private IP Addressing

- One of the problems in IP network address allocation is that many hosts do not require access to hosts in other networks $\Rightarrow$ Assigning Globally unique public IP addresses for such hosts may be wasteful
- IETF proposed the use of Private IP addresses that are not advertised outside the private network.

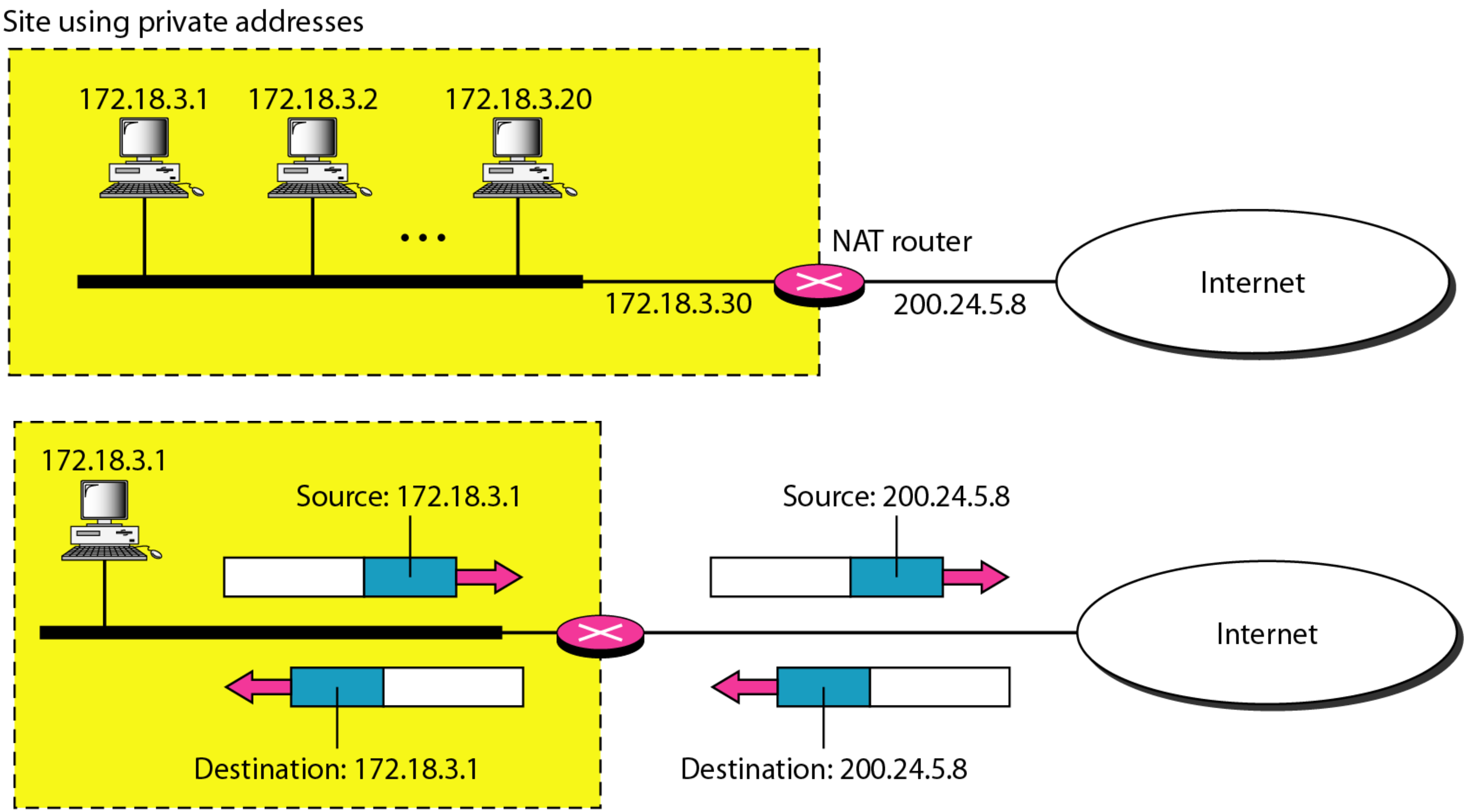
Range			*Total*
10.0.0.0	to	10.255.255.255	2^{24}
172.16.0.0	to	172.31.255.255	2^{20}
192.168.0.0	to	192.168.255.255	2^{16}

Private IP Addresses are non-routable

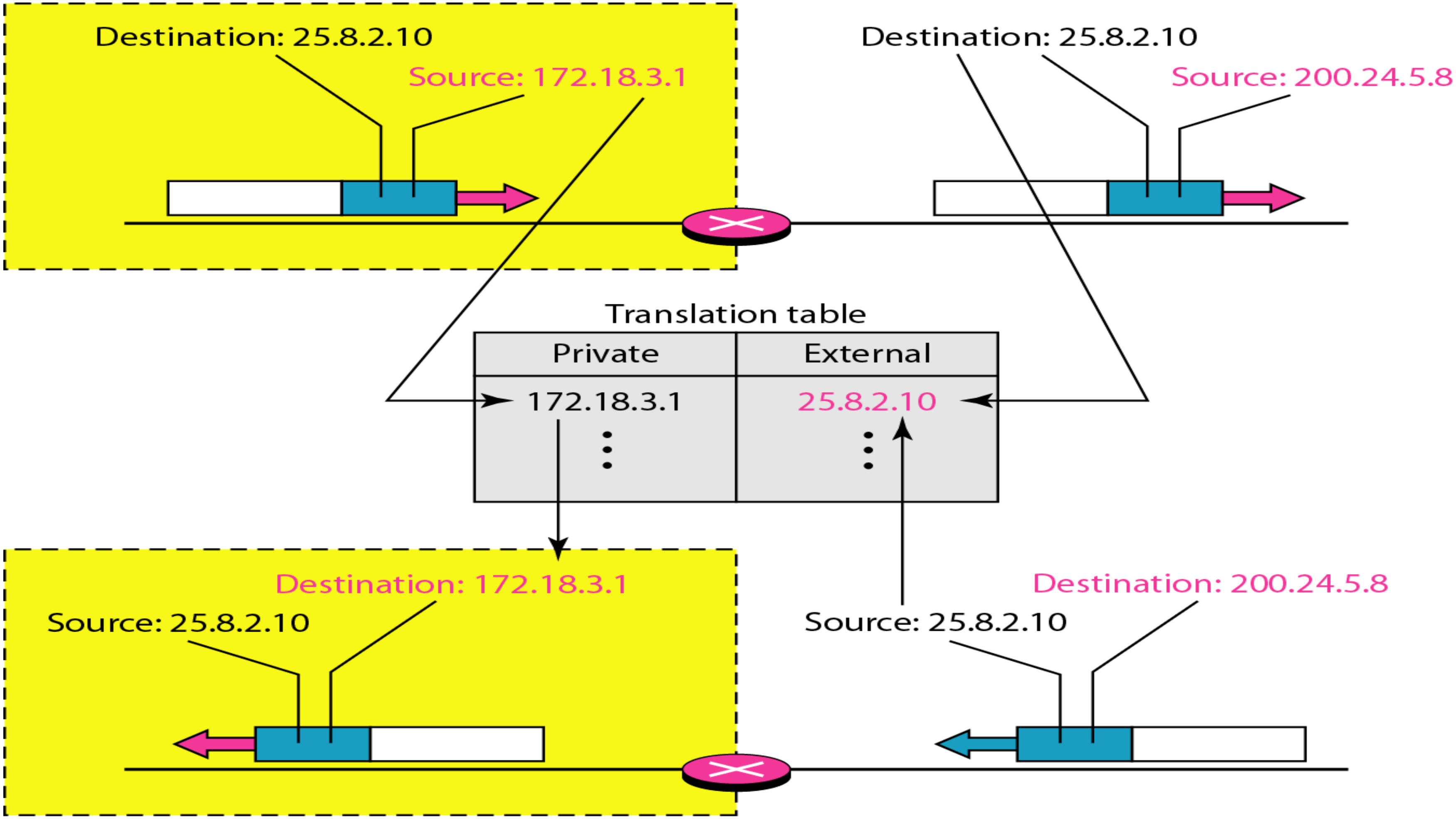
NAT: Network Address Translation

- NAT is a protocol that maintains a translation table for mapping an internal private IP address to a globally unique IP addresses and vice versa
- May be static (one-to-one) or dynamic (from a pool of global IP addresses)
- Implemented in the border (access) router separating the private network and the public Internet or as a stand-alone multi-homed Server
- NAT is a special type of Proxy Server. It was introduced with Windows 2000

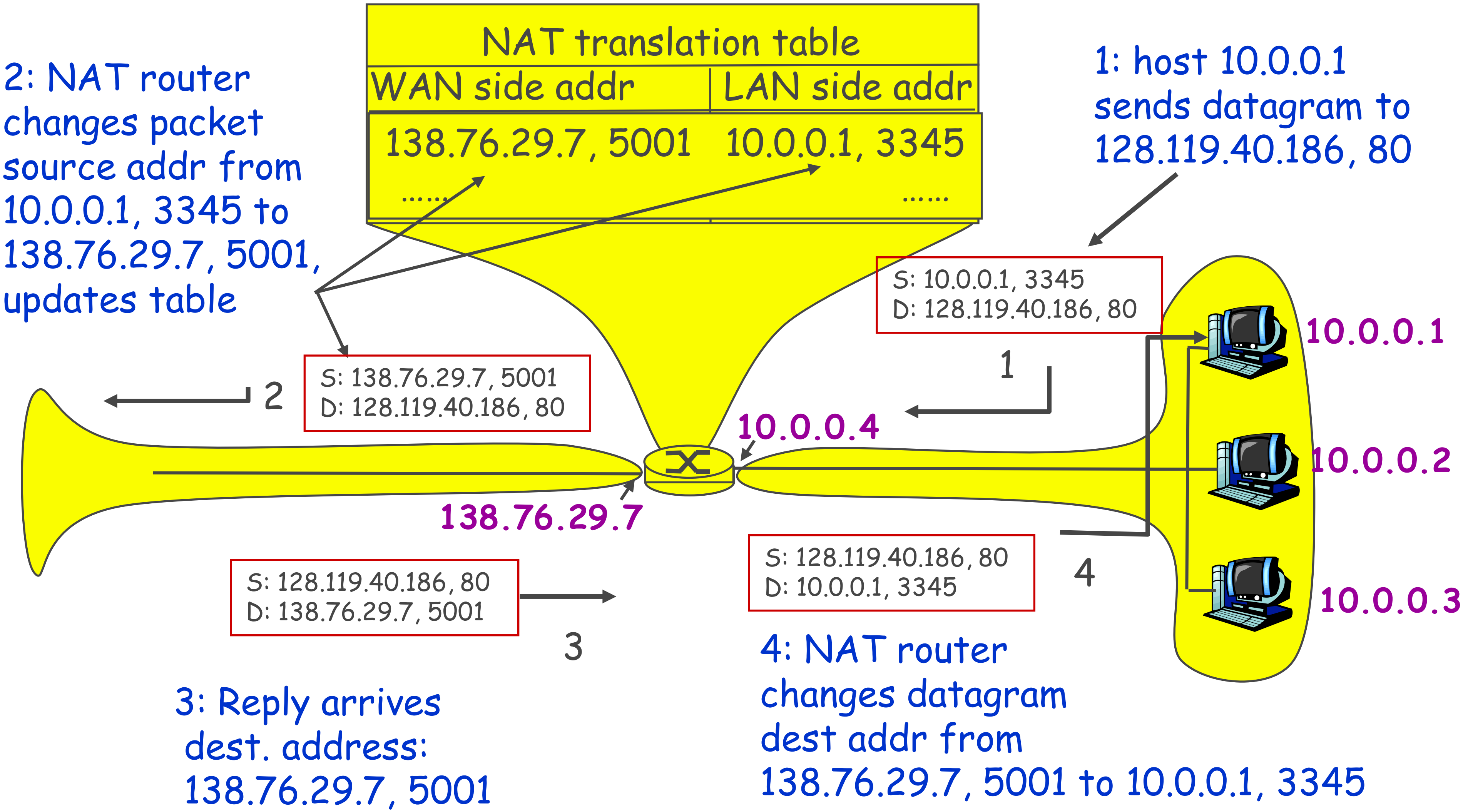
NAT Implementation



NAT Address Translation



NAT & PAT



NAT translation table
WAN side addr
LAN side addr
138.76.29.7, 5001
10.0.0.1, 3345
……
……
2: NAT router changes packet source addr from 10.0.0.1, 3345 to 138.76.29.7, 5001, updates table
1: host 10.0.0.1 sends datagram to 128.119.40.186, 80
S: 10.0.0.1, 3345
D: 128.119.40.186, 80
1
S: 138.76.29.7, 5001
D: 128.119.40.186, 80
2
10.0.0.4
10.0.0.1
10.0.0.2
10.0.0.3
138.76.29.7
S: 128.119.40.186, 80
D: 10.0.0.1, 3345
4
S: 128.119.40.186, 80
D: 138.76.29.7, 5001
3
3: Reply arrives dest. address: 138.76.29.7, 5001
4: NAT router changes datagram dest addr from 138.76.29.7, 5001 to 10.0.0.1, 3345

Motivation for NAT

- 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 or visible by outside world (a security plus)

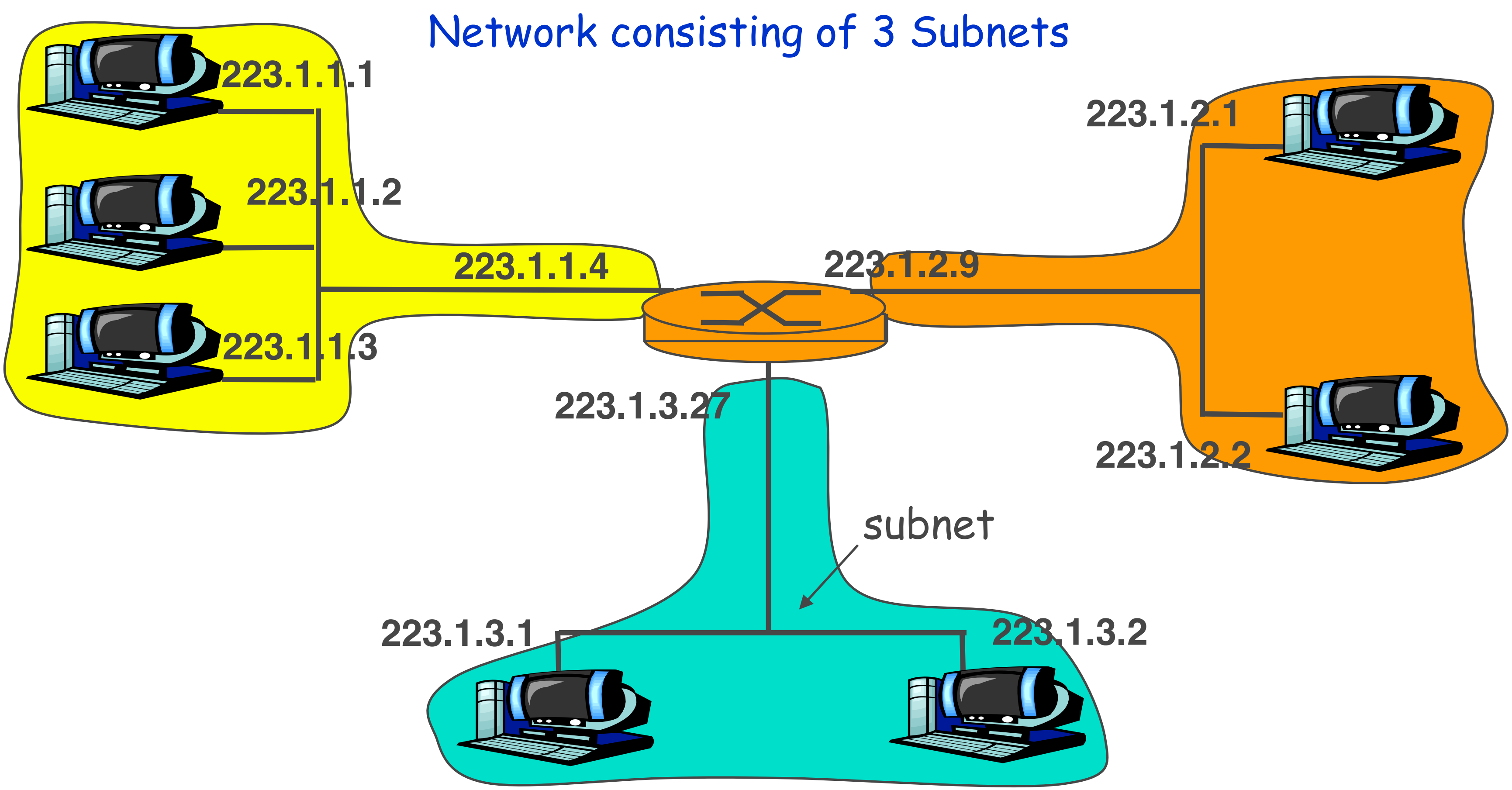
Subnetting

- Subnetting is the process of creating multiple segments within a single IP network address space
- From the perspective of a node outside the network, all nodes on any of the subnetworks appear to be on the original single network
- Internet routing tables are not affected by subnetting, I.e. routing tables need not be overloaded with information about routes to all internal subnets, just information to the access router/gateway

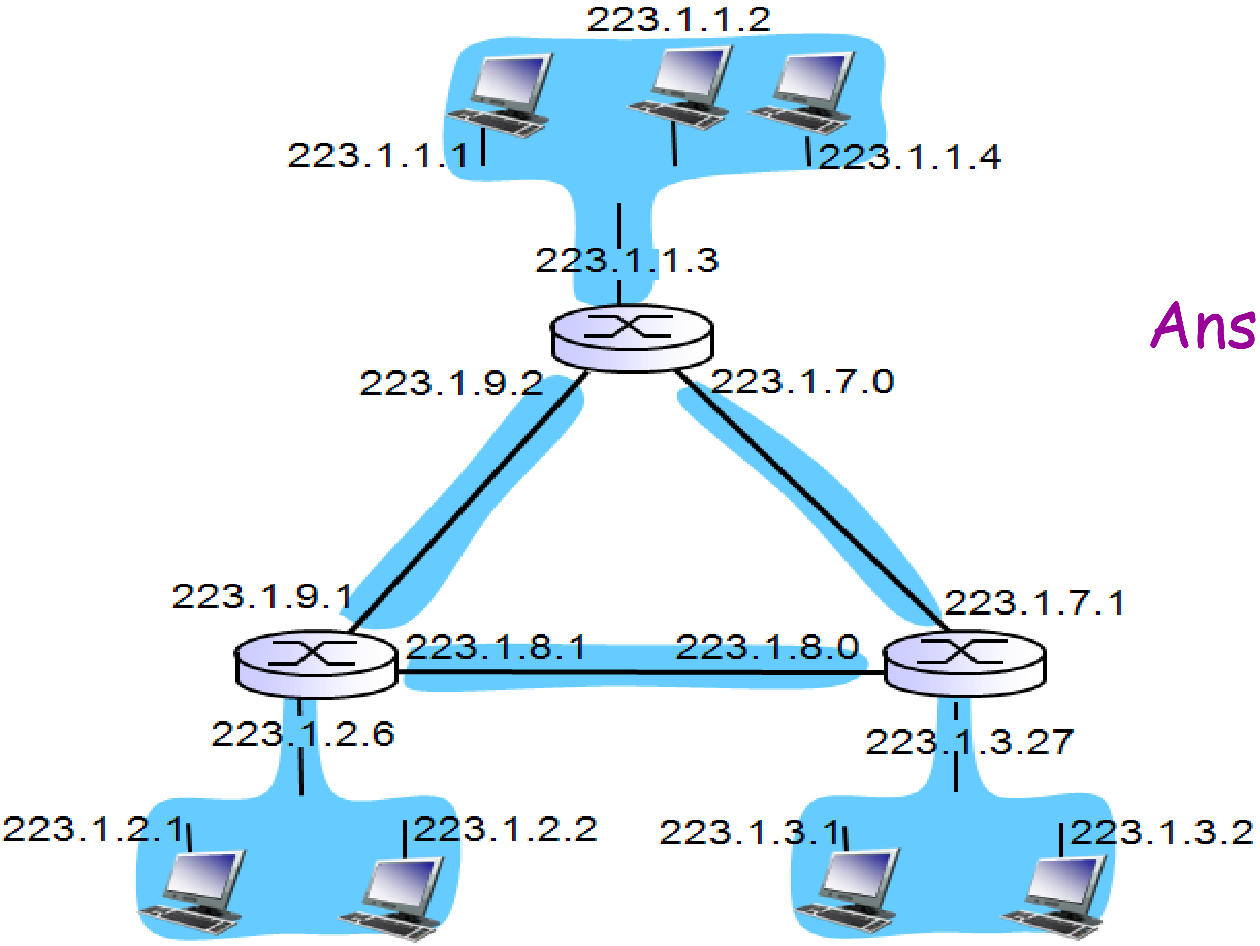
Subnetting (Continued)

- Classes A, B and C in IP addressing are designed with two levels of hierarchy (netid & hostid)
- Problem: An organization with a class B address can not have more than network and all 2^{16} hosts are attached to that network $\Rightarrow$ A nightmare in managing this network, single broadcast domain, security issues, etc…
- Subnetting create another level of hierarchy (netid, subnetid and hostid). Delivery of IP packets involves three steps; <u>delivery to the site router</u>, <u>delivery to the subnet router</u>, <u>delivery to the host</u>

Example of Subnetting



Example of Subnetting (How many?)



Answer:

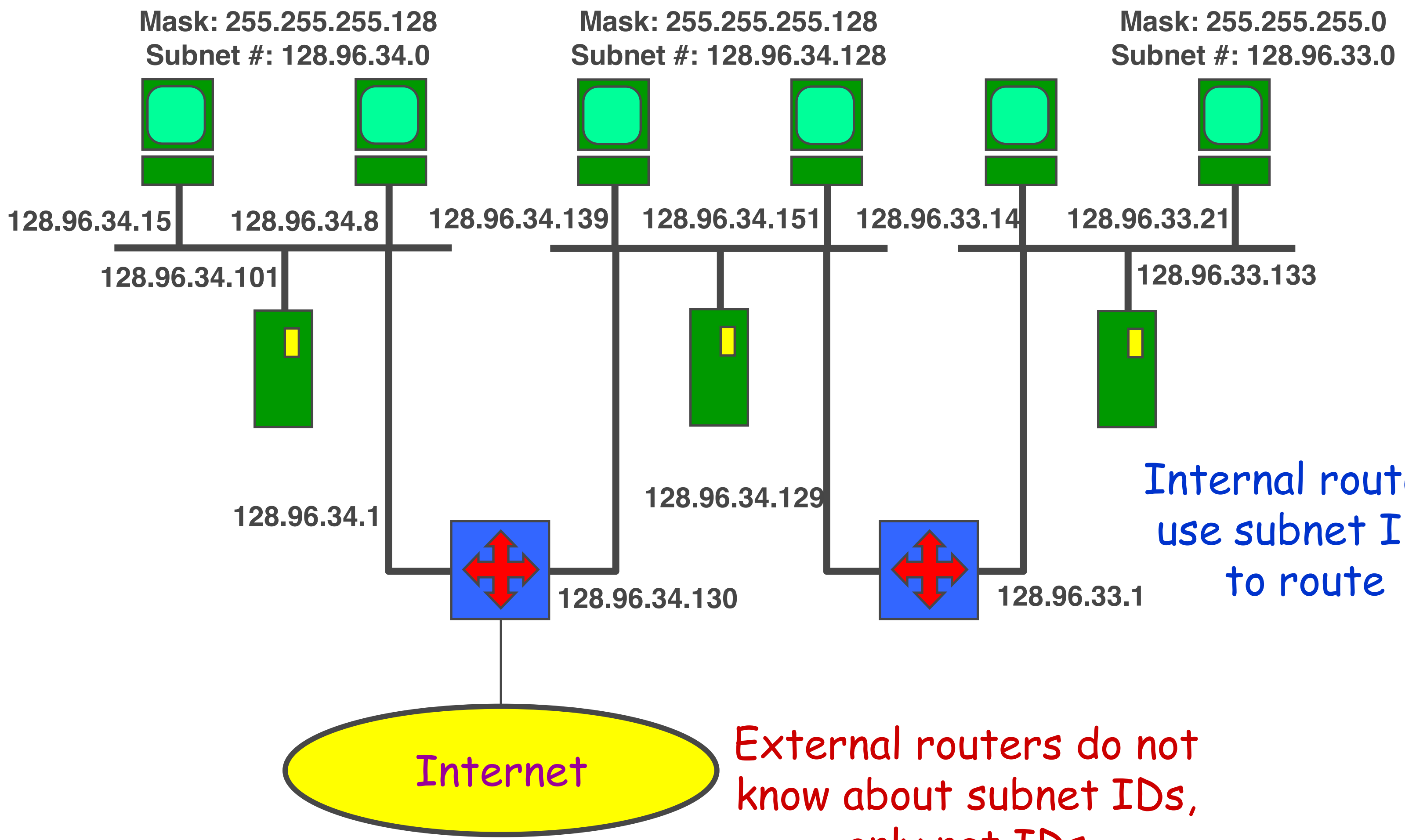
Subnet Masking

- Subnetting is achieved by "stealing" some bits from the hostid field to represent the subnet portion of the address
- Those bits that are used for the subnetid are identified through the use of a subnet mask
- Masking is the process of extracting the address of the physical network (if subnetting is not used) or the subnet address (if subnetting is used) from an IP address
- A subnet mask is a 32-bit pattern having a "1" in every netid and subnetid locations and a "0" in every hostid location

Subnet Masking (Continued)

- Subnet masking is performed (both at the host and at the router) by applying "bit-wise-AND" operation between the IP address and the subnet mask
- Example 1: Class B network without subnetting
  - 141.14.2.21 10001101.00001110.00000010.00010101
  - 255.255.0.0 11111111.11111111.00000000.00000000
  - "Bit-wise and" 10001101.00001110.00000000.00000000

Example of Subnetting



Internal routers use subnet IDs to route

External routers do not know about subnet IDs, only net IDs

Subnet Router Routing Table

Partial Table in Router 128.96.33.1

Subnet Number	Subnet Mask	Next Hop
128.96.34.0	255.255.255.128	Left Router
128.96.34.128	255.255.255.128	Left Interface
128.96.33.0	255.255.255.0	Right Interface

```
for each table entry do
  if (DestAddr & Subnet Mask) = SubnetNumber
    if NextHop is an Interface
      deliver packet directly to DestAddr
    else
      deliver packet to Router
```

Classless IP Addressing

- To overcome IP Address depletion and allow more organizations ability to access the Internet
- Get rid of classes and assign addresses in "Blocks". The size of the block (The # of IP addresses in the block) depends on the organization demand
- There are some restrictions on these blocks

Restrictions of Address Blocks

- The number of addresses in a block must be a power of 2 (1, 2, 4, 8, etc…)
- The addresses in the block are contiguous, i.e. one after the other
- The first address in the block (in decimal) must be divisible by the size of the block

CIDR Notation

CIDR: Classless Inter Domain Routing

- Network and Subnet portions of address of arbitrary length
- address format: a.b.c.d/x, where x is # bits in network and subnet portion of address

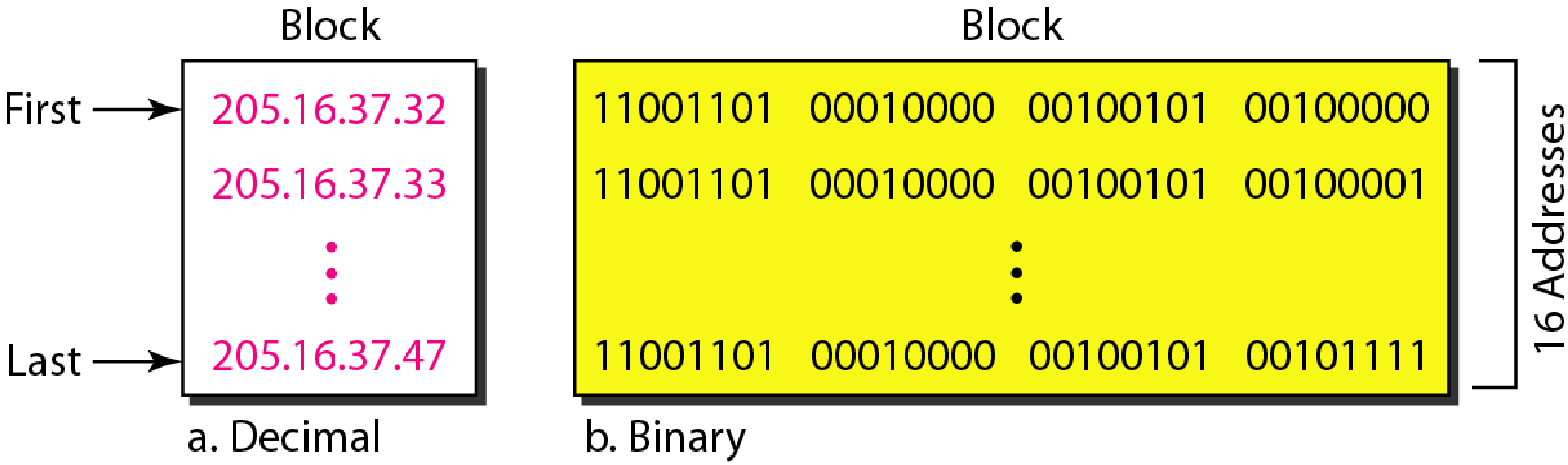
200.23.16.0/23

11001000 00010111 00010000 00000000

Subnet part — Host part

subnet mask: /23 or 255.255.254.0

Example: A block of Size 16



In IPv4 addressing, a block of addresses can be defined as w.x.y.z /n in which w.x.y.z defines one of the addresses and the /n defines the mask. The number of address in the block is 2^{32-n}

The <u>first address</u> in the block can be found by setting the rightmost 32 – n bits to 0s. Hence the first address in the block represents the Network/Subnet address of the organization

The <u>last address</u> in the block can be found by setting the rightmost 32 – n bits to 1s. Hence the last address in the block represents the broadcast address in the organization network

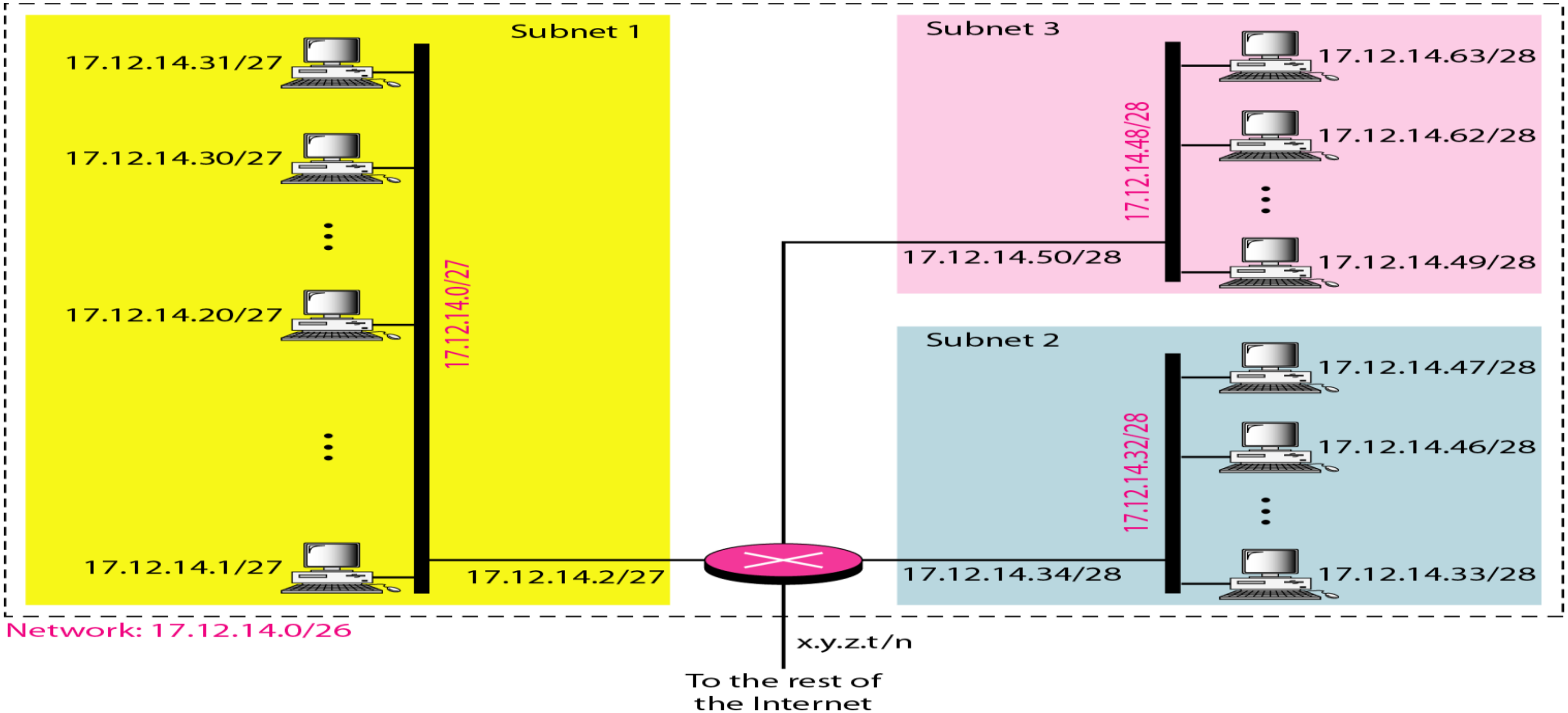
Example of Classless IP Addressing

- An ISP gets a block of IP addresses. The Block is 200.23.16.0/20 . The size of the block is $2^{12} = 4096$. The ISP has 8 customers (organizations), each requiring a "block" of size 512

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

Example of Classless IP Addressing

- Organization was assigned a block 17.12.40.0/26 (Size of block is 64).Organization has three departments. Three subnets of sizes 32, 16 and 16



Hierarchical Addressing

Hierarchical addressing allows efficient advertisement of routing information