CS348: Computer Networks

Network Layer
Introduction

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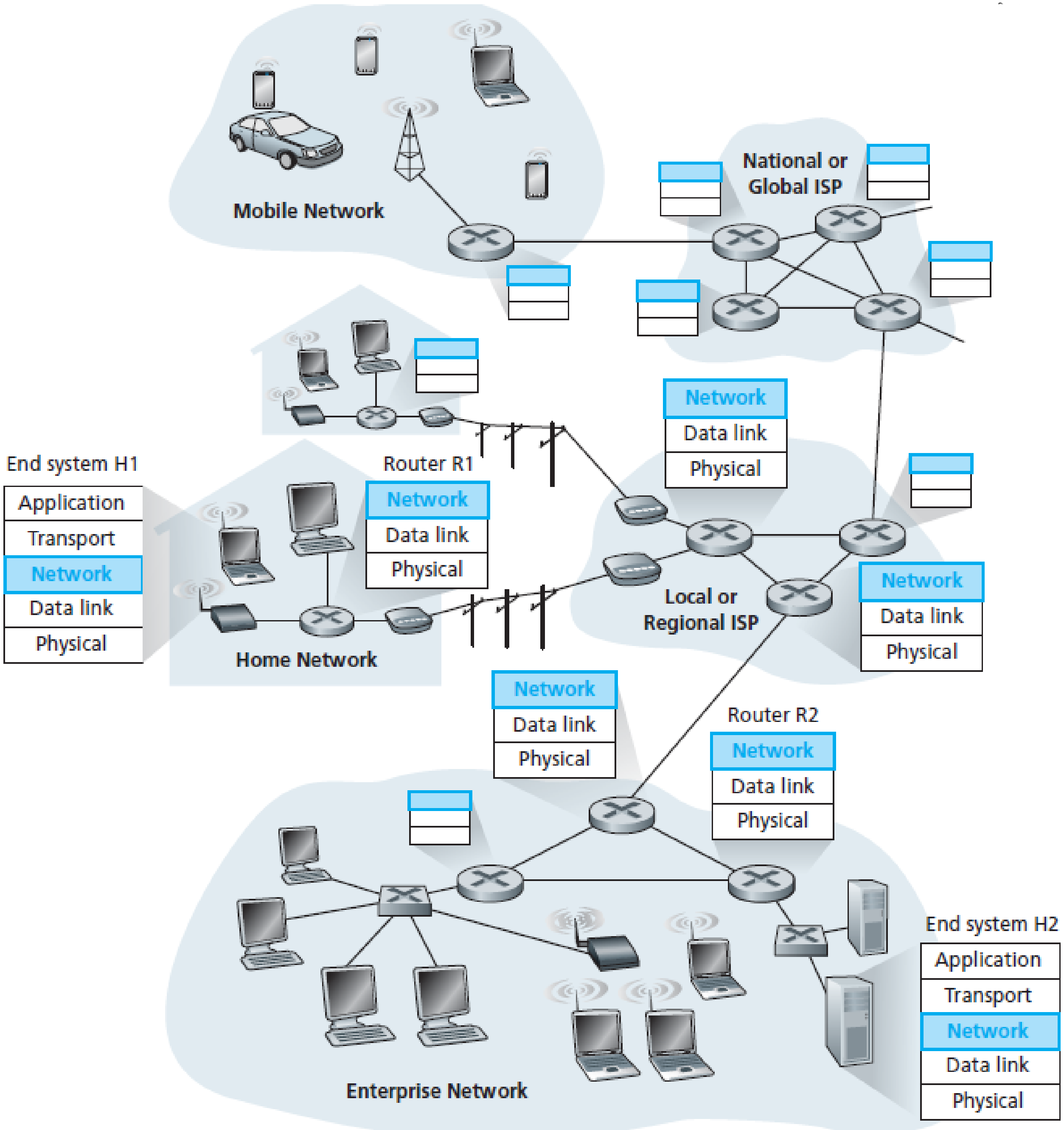
Introduction

Network Layer is responsible for host-to-host delivery of packets.



Network Service Models

- It defines the characteristics of end-to-end transport of packets

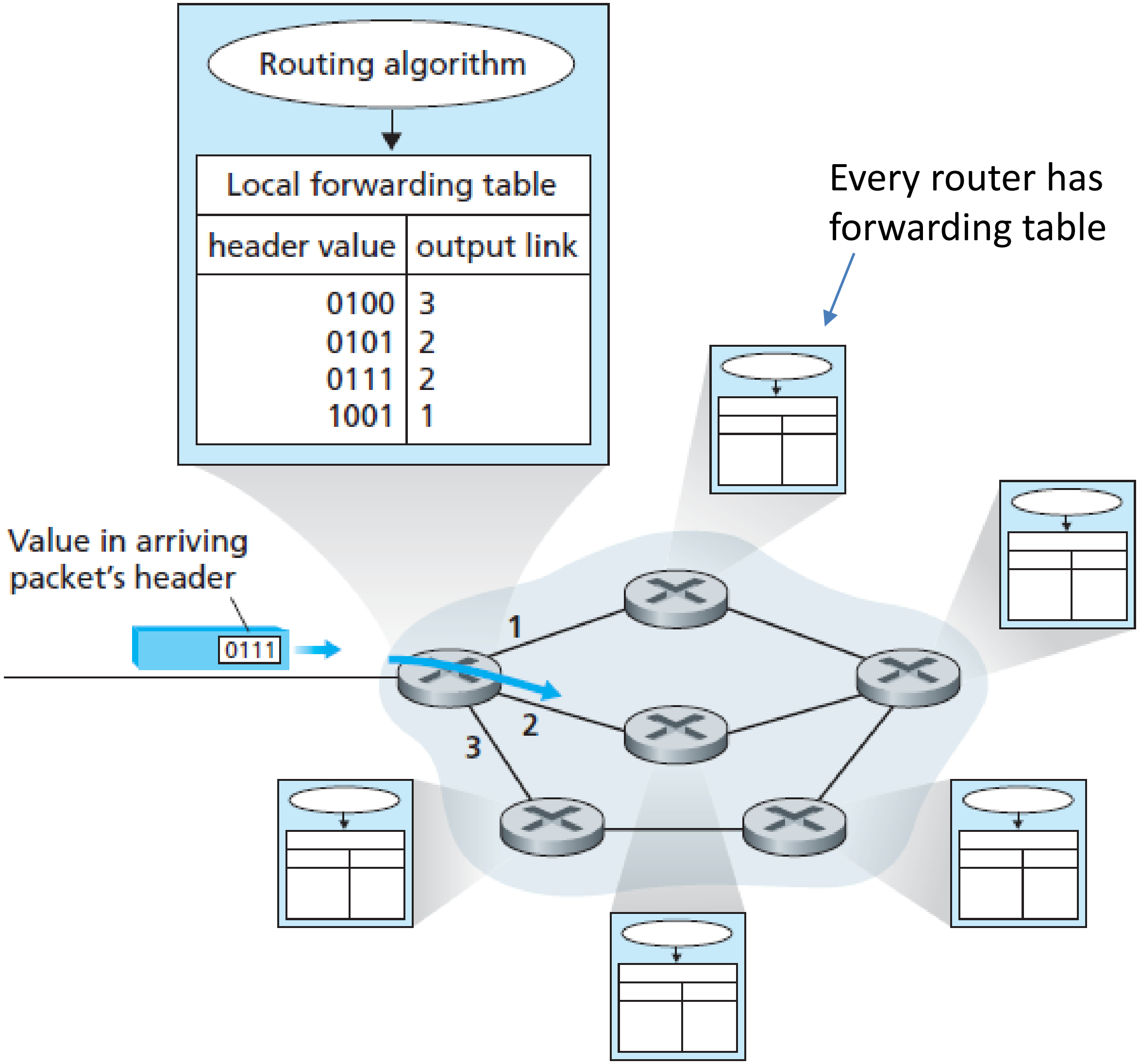
- Few services that can be provided by Network Layer
  - Guaranteed delivery
  - Guaranteed delivery with bounded delay
  - In-order packet delivery
  - Guaranteed minimum bandwidth
  - Guaranteed maximum jitter
  - Security Service
  - Congestion Indication

- eventual delivery of transmitted packets are not guaranteed
- timing between packets is not guaranteed to be preserved
- packets are not guaranteed to be received in order

Network Architecture	Service Model	Bandwidth Guarantee	No-Loss Guarantee	Ordering	Timing	Congestion Indication
Internet	Best Effort	None	None	Any order possible	Not maintained	None
ATM	CBR	Guaranteed constant rate	Yes	In order	Maintained	Congestion will not occur
ATM	ABR	Guaranteed minimum	None	In order	Not maintained	Congestion indication provided

Forwarding and Routing

- **Forwarding** involves the transfer of a packet from an incoming link to an outgoing link within a *single* router
- It is the router-local action of transferring a packet
- **Routing** involves *all* of a network's routers, whose collective interactions via routing protocols determine the paths that packets take on their trips from source to destination node.
- It is the network-wide process that determines the end-to-end paths
- **Routing algorithms** determine values in **forwarding** tables
- Routing algorithm may be centralized or distributed

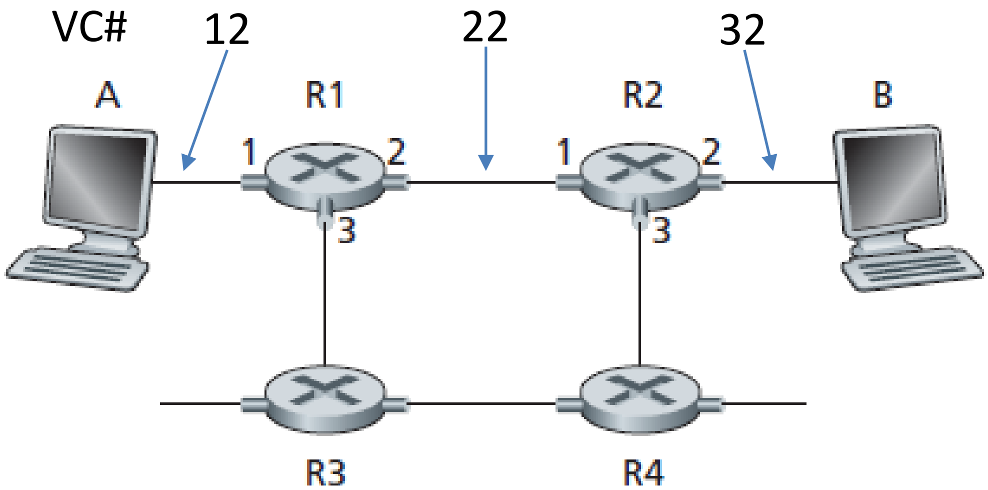


Connection(less) Service

- **Transport layer** can offer connectionless service or connection-oriented service between two processes.
- **Network layer** can provide connectionless service or connection service between two hosts.
- Network-layer services in many ways parallel transport-layer services. But, there exist crucial differences:

In Network Layer	In Transport Layer
Provide host-to-host service	Provide process-to-process services
Can't provide both together - Virtual-circuit network (e.g. ATM, Frame Relay) - Datagram network (e.g. Internet)	Can provide both connection together
Implemented in the routers as well as in the end systems	Implemented at the edge of the network or in the end systems

Virtual-Circuit Network



Incoming Interface	Incoming VC #	Outgoing Interface	Outgoing VC #
1	12	2	22
2	63	1	18
3	7	2	17

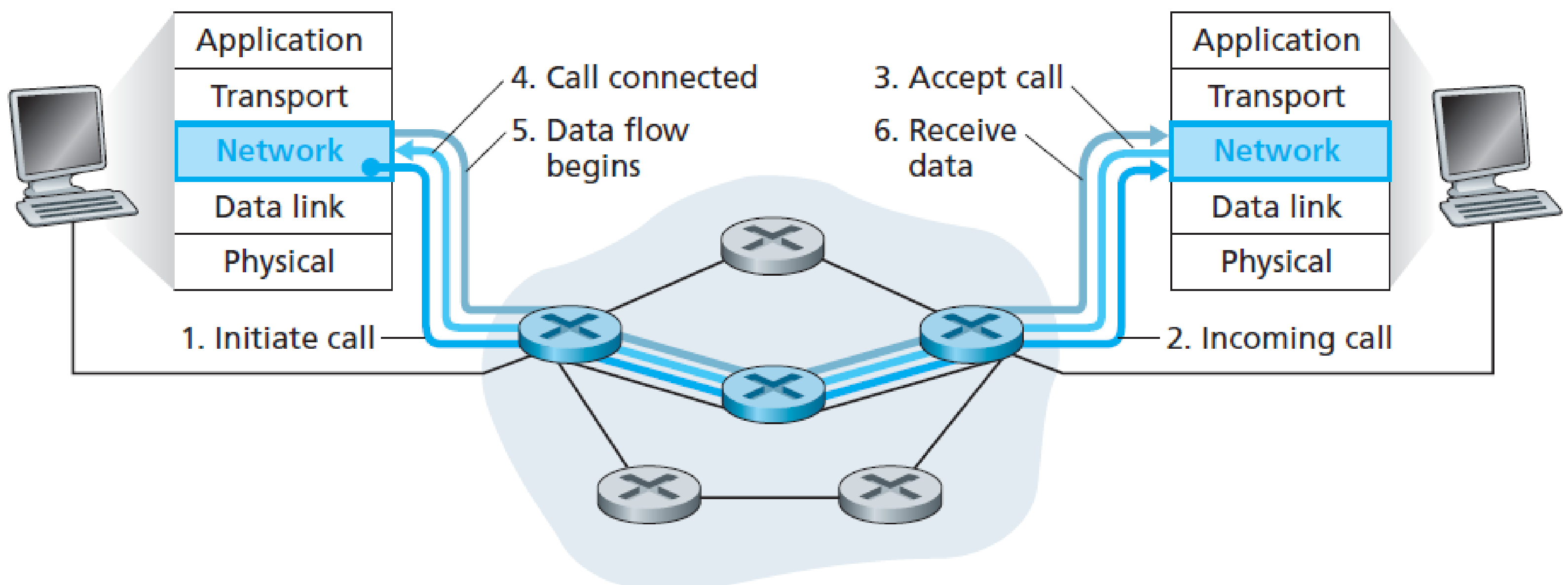
Forwarding Table for R1

- Network layer connections are called virtual circuits (VCs).
- A VC consists of
  - (1) a path (i.e., a series of links and routers) between the source and destination hosts
  - (2) VC numbers, one number for each link along the path,
  - (3) entries in the forwarding table in each router along the path.
- A virtual circuit may have a different VC number on each link
- A packet belonging to a virtual circuit will carry a VC number in its header.

Cont…

- Three identifiable phases in a virtual circuit
  - *VC setup*
  - *Data transfer*
  - *VC teardown*

- VC setup at the network layer v/s connection setup at the transport layer
  - During transport-layer connection setup, the two end systems alone determine the parameters of their transport-layer connection.
  - With a VC network layer, routers along the path between the two end systems are involved in VC setup, and each router is fully aware of all the VCs passing through it.

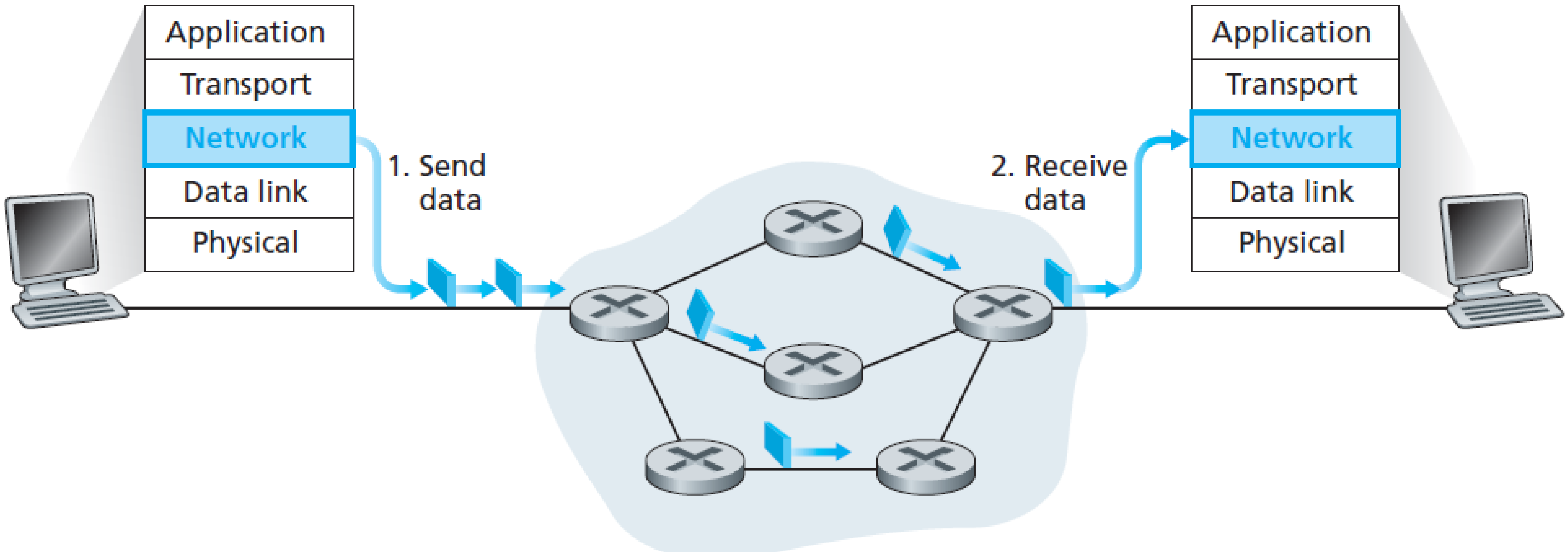


Datagram Network

- each time an end system wants to send a packet, it stamps the packet with the address of the destination end system
- the router matches a **prefix** of the packet's destination address with the entries in the table
- When there are multiple matches, the router uses the **longest prefix matching rule**

A forwarding table of router R1

Prefix Match	Link Interface
11001000 00010111 00010	0
11001000 00010111 00011000	1
11001000 00010111 00011	2
otherwise	3

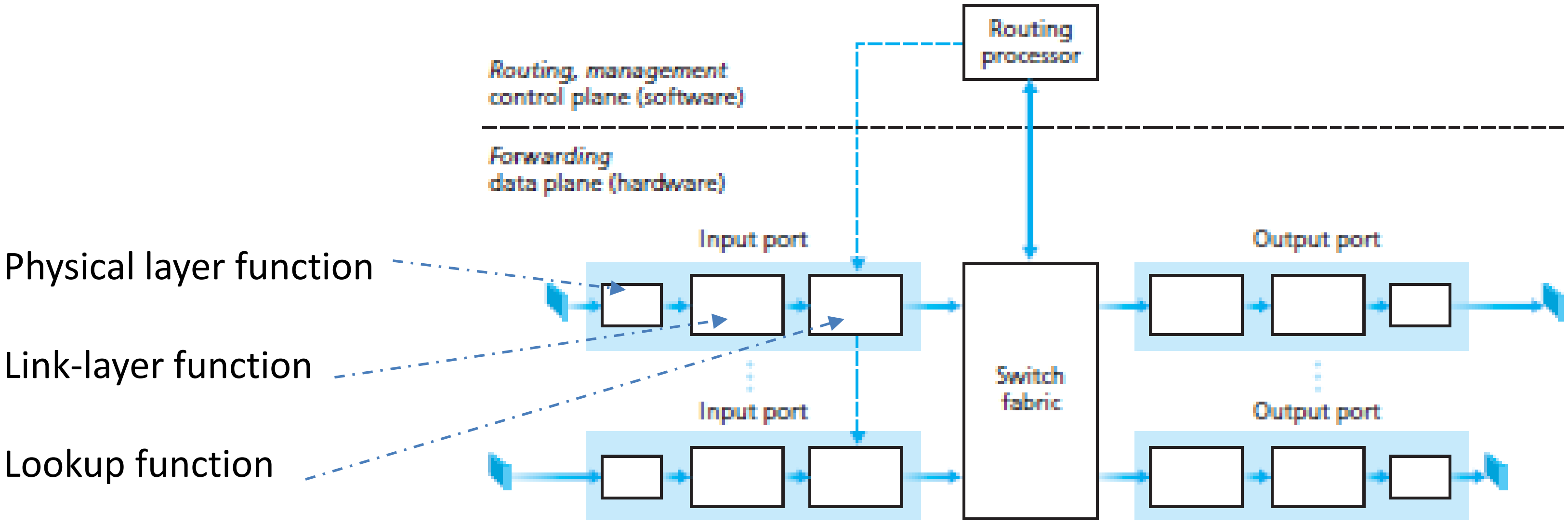


Cont…

- In a VC network,
  – a forwarding table in a router is modified whenever a new connection is set up through the router or whenever an existing connection through the router is torn down.

- In a Datagram network,
  – forwarding tables can be modified at any time.
  – So, packets may follow different paths through the network and may arrive out of order.

Router Architecture



High-level view of a generic router architecture

- Input Ports
- Switching fabric
- Output Ports
- Routing processor

- SDN: Software Defined Networking
  - Decouples the Data plane and Control plane

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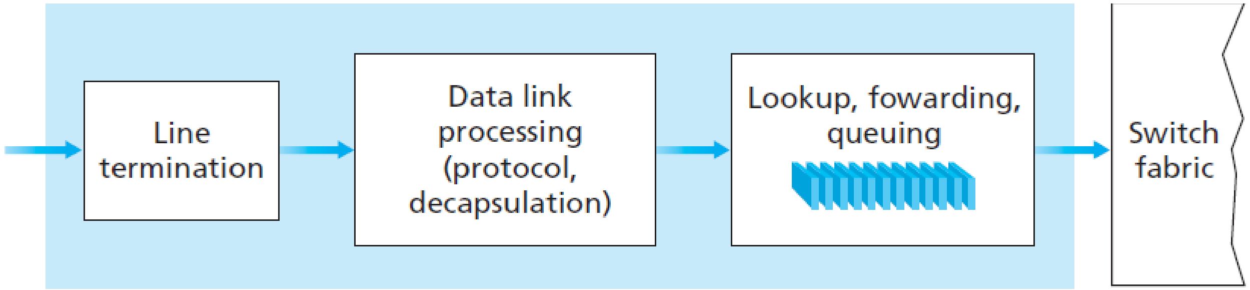

Figure 4.7 ♦ Input port processing

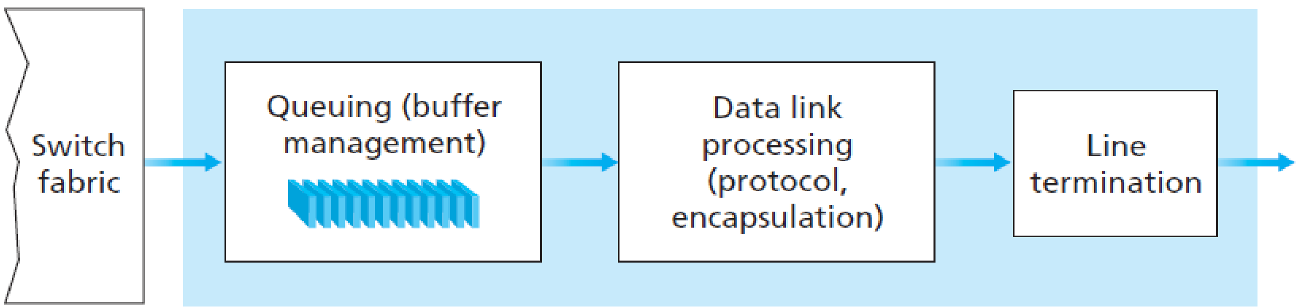

Figure 4.9 ♦ Output port processing

- Buffer Management
  - **Drop-tail queuing** (i.e. drop the arriving packets from tail)
  - **Selective drop** (i.e. drop one already queued packet using some scheduling policy)
  - **Active Queue Management** (i.e. drop/mark a packet before the buffer is full. e.g., Random Early Detection (RED))

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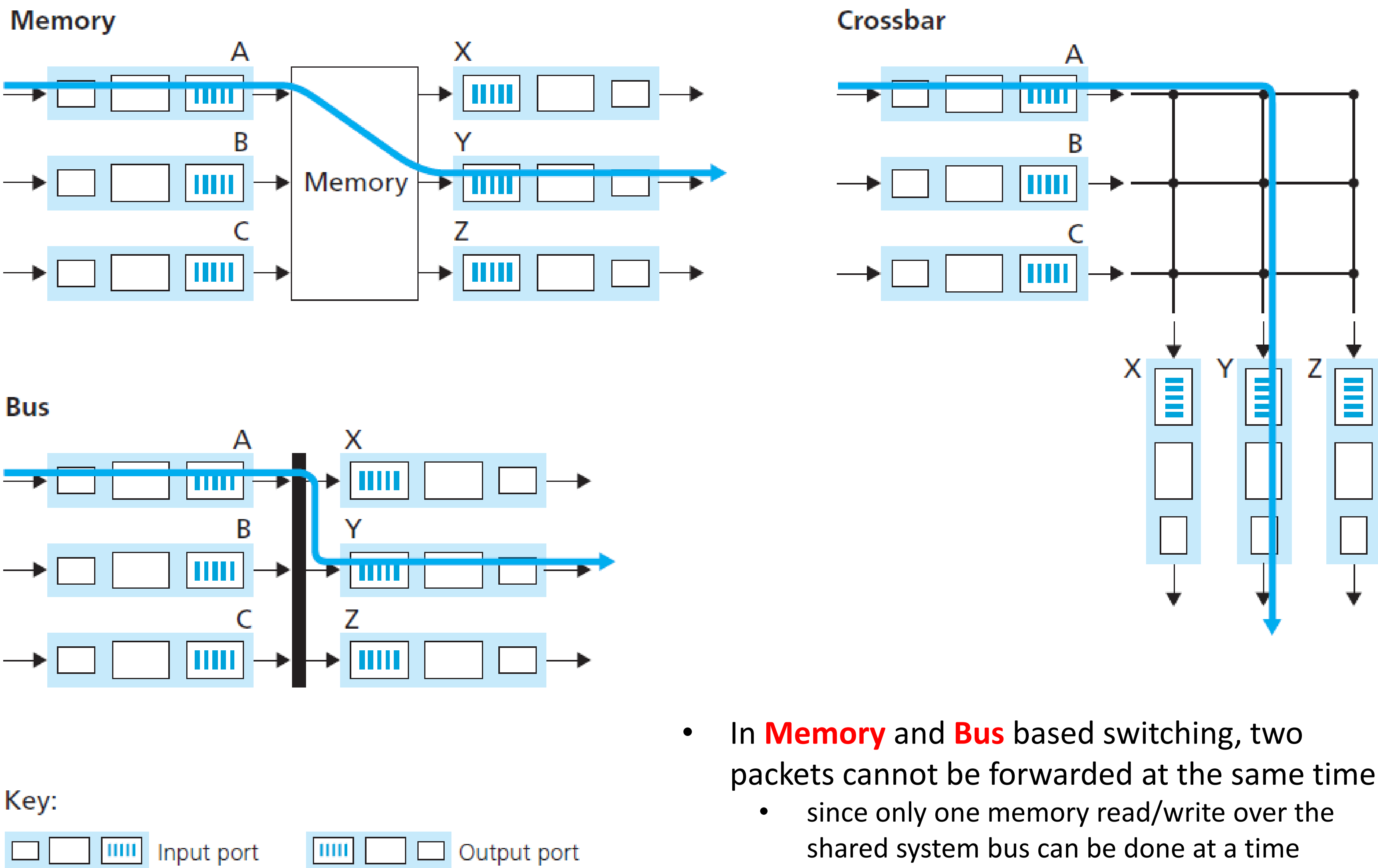
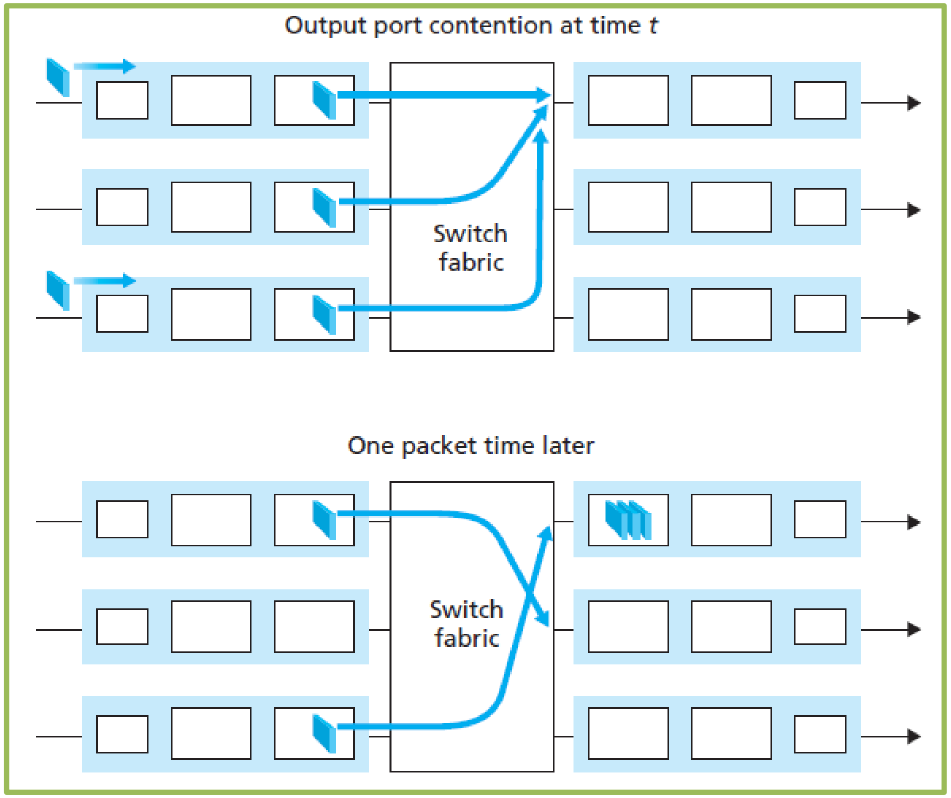


Figure 4.8 ♦ Three switching techniques

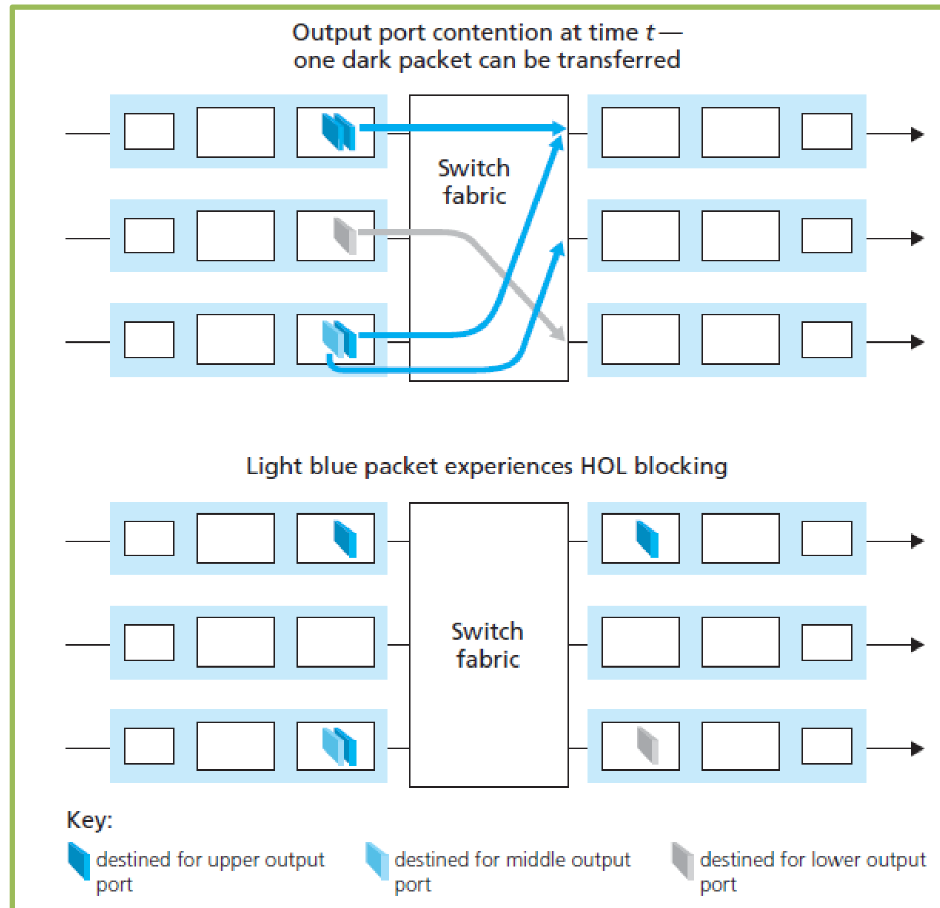
- In **Memory** and **Bus** based switching, two packets cannot be forwarded at the same time.
  - since only one memory read/write over the shared system bus can be done at a time
- **Crossbar** switching can forward multiple packets

Where Does Queueing Occur?

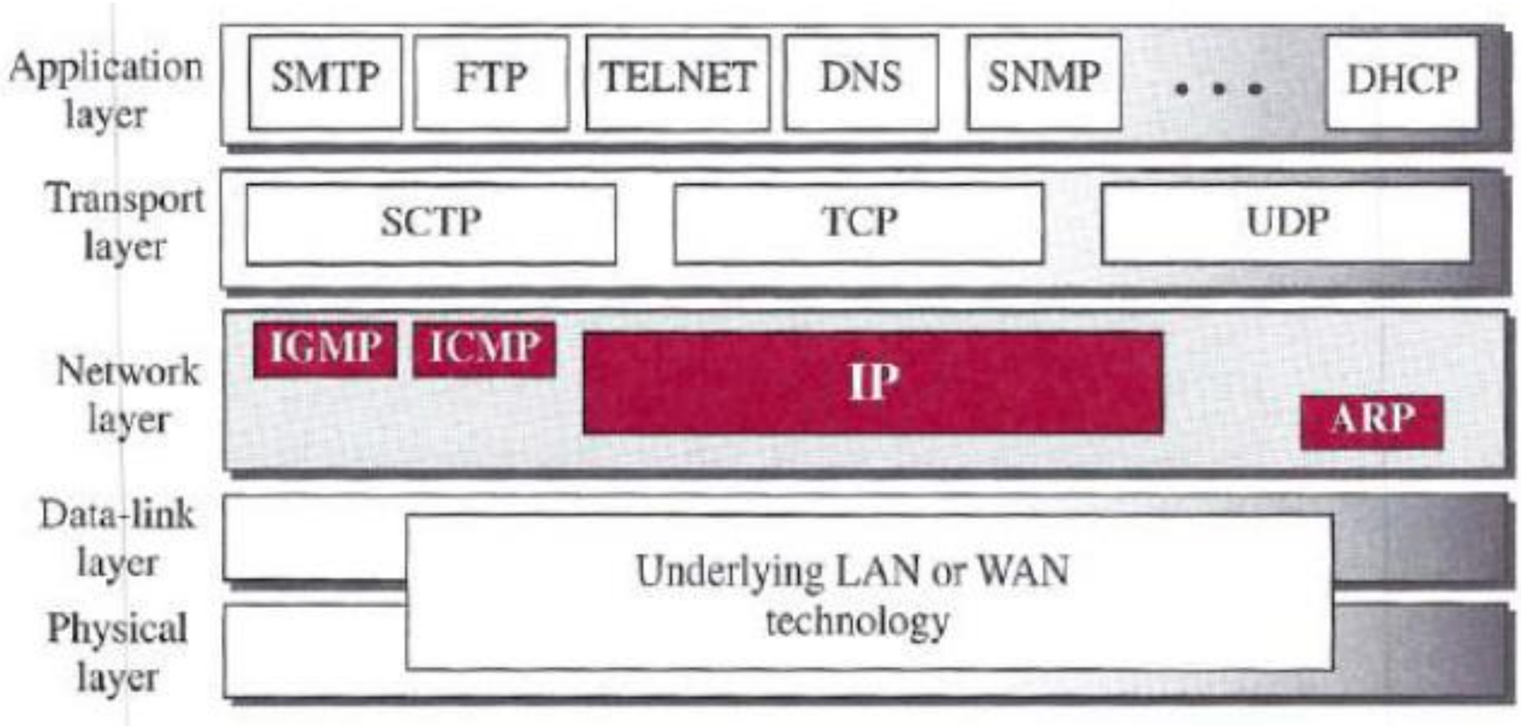


Output port queuing

HOL blocking at an **input port** queued switch



TCP/IP Protocol Suite



- IP Addressing
- IP Packet format
- Routing Protocol
- Forwarding Rules

Internet's Network Layer

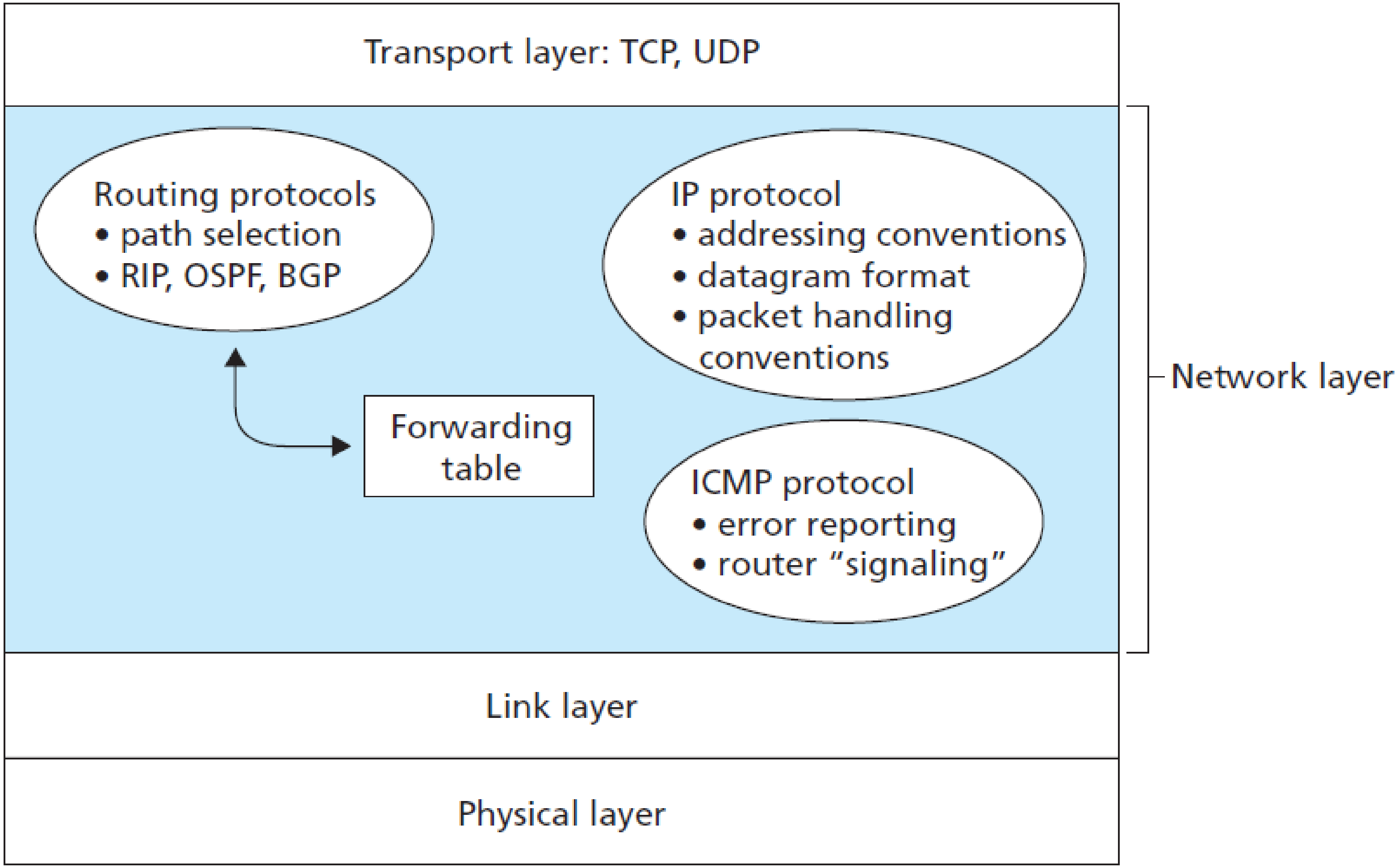
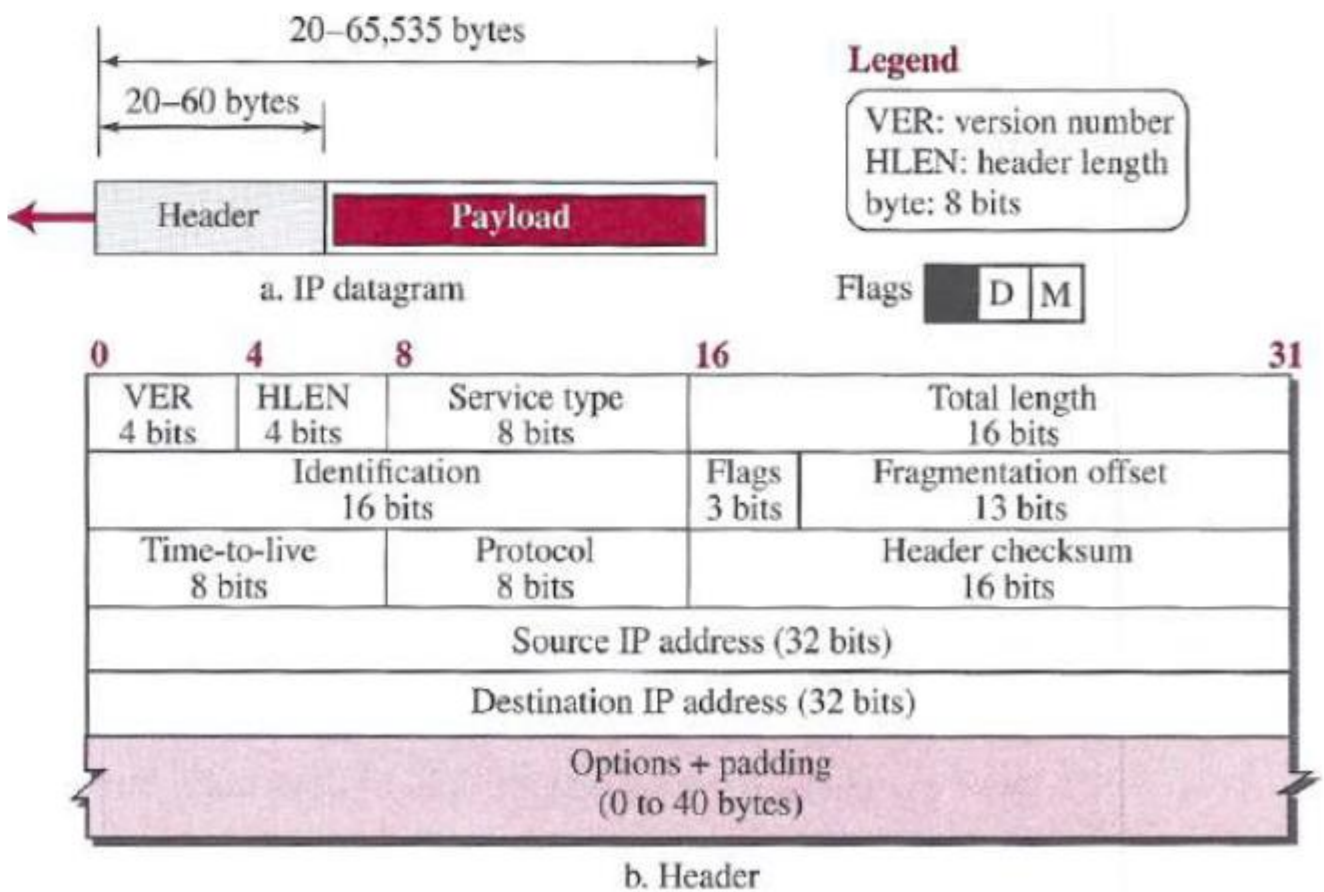


Figure 4.12 ♦ A look inside the Internet's network layer

IPv4 Header

- The most widely used protocol for internetworking is the Internet Protocol (IP).



IP Datagram Fields

- VER: version of the IPv4 protocol
- HLEN: total length of the datagram header
- ToS: provides *differentiated services* (DiffServ)
- Total length: header + data in byte

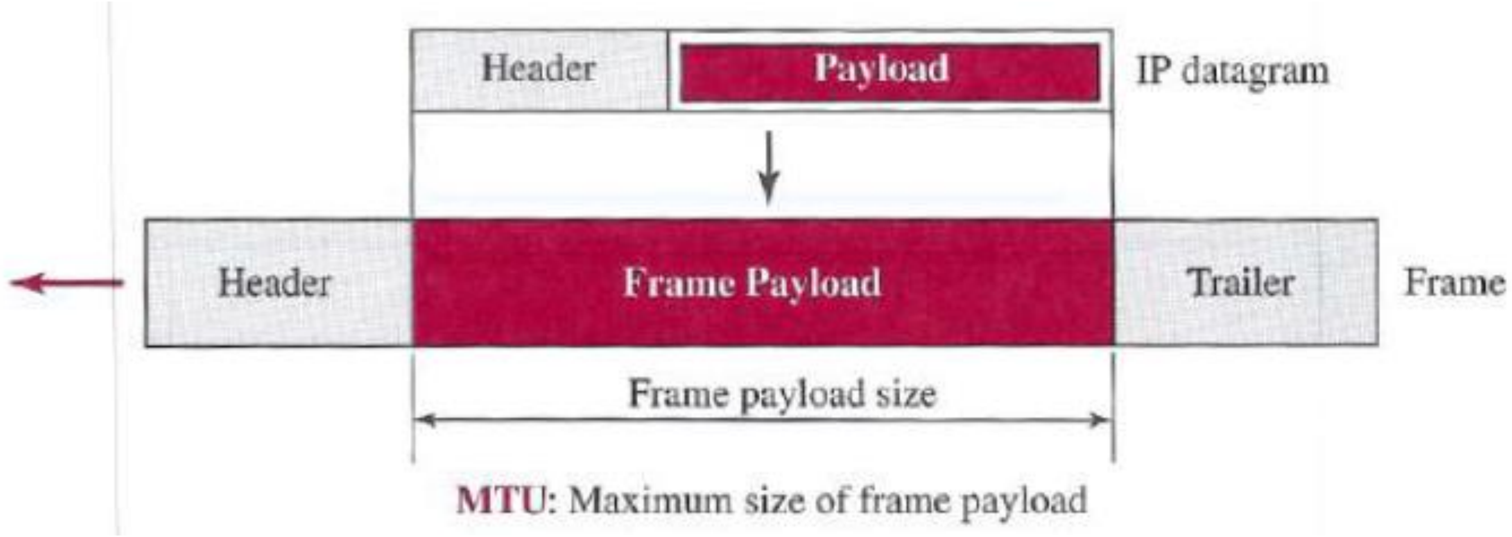
- Identification, Flags, Fragmentation Offset: These three fields are related to the fragmentation of the IP datagram
- TTL: control the maximum number of hops (routers) visited by the datagram

- Protocol: it defines to which protocol the payload should be delivered
- Checksum: helps to check the error in datagram header only
- Source & Destination Address: 32 bit IP addresses

- Options & Padding: used for network testing and debugging
- Payload: the packet coming from other protocols that use the service of IP

IP Fragmentation & Reassembly

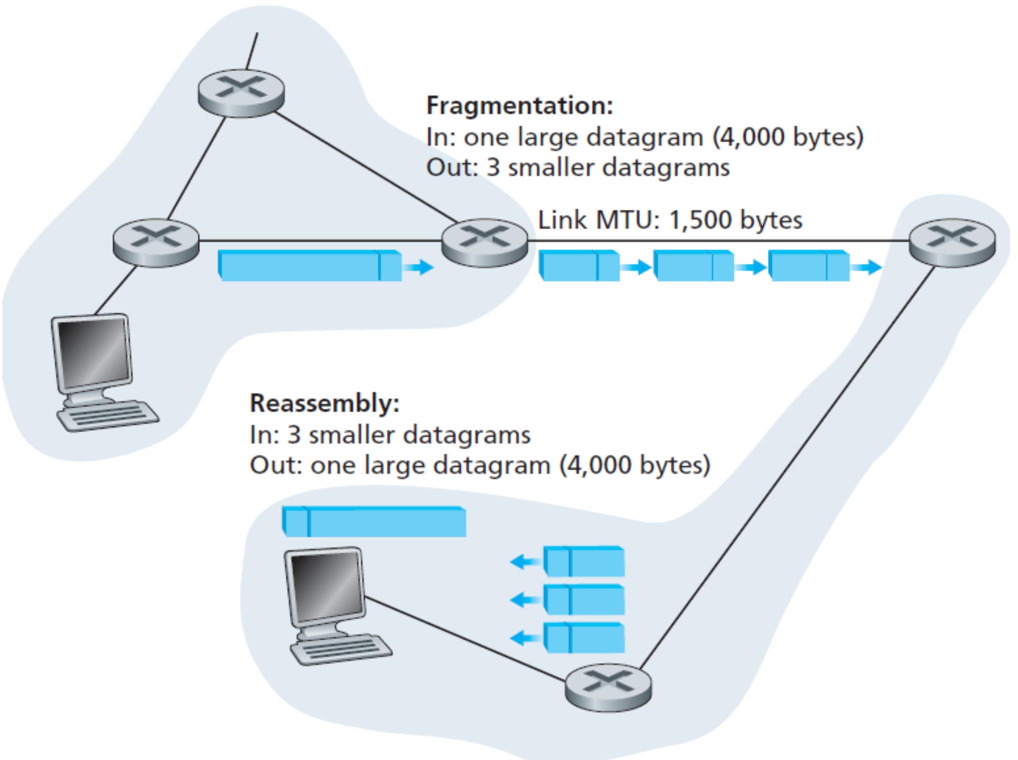
- A datagram can travel through different networks.
- Each router
  - decapsulates the IP datagram from the frame it receives,
  - processes it, and then
  - encapsulates it in another frame.



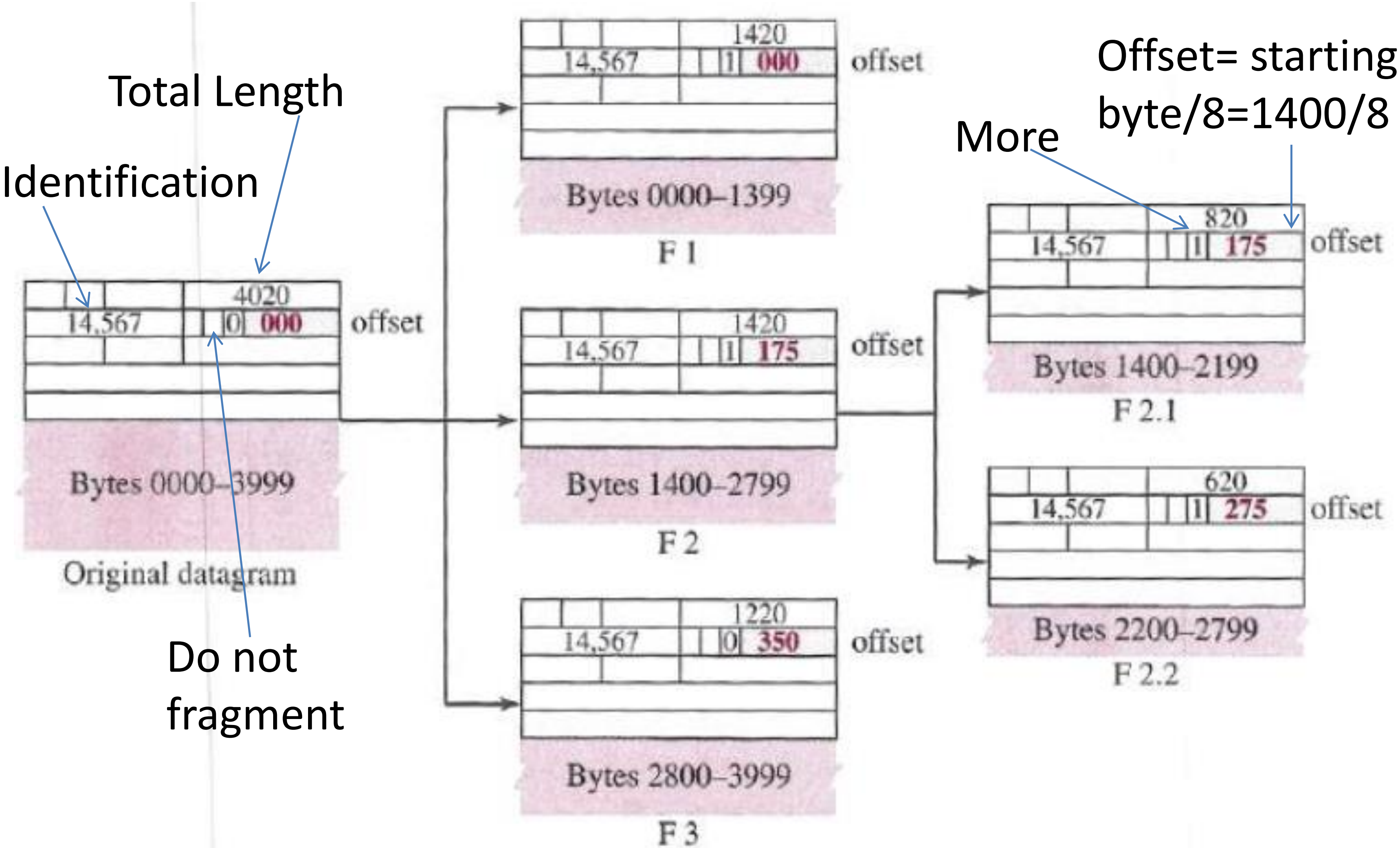
Cont…

- **Fragmentation** is done by the source host or intermediate router.
- But, **Reassembly** is done by the destination host only.

- 16-bit *identification field:* identifies a datagram uniquely. This is the present value of a counter maintained by sender.
- 3-bit flags *field:*
  - *Not used,*
  - *D: do not fragment,*
  - *M: more fragment*
- 13-bit *fragmentation offset field:* shows the relative position of a fragment w.r.t. the whole datagram



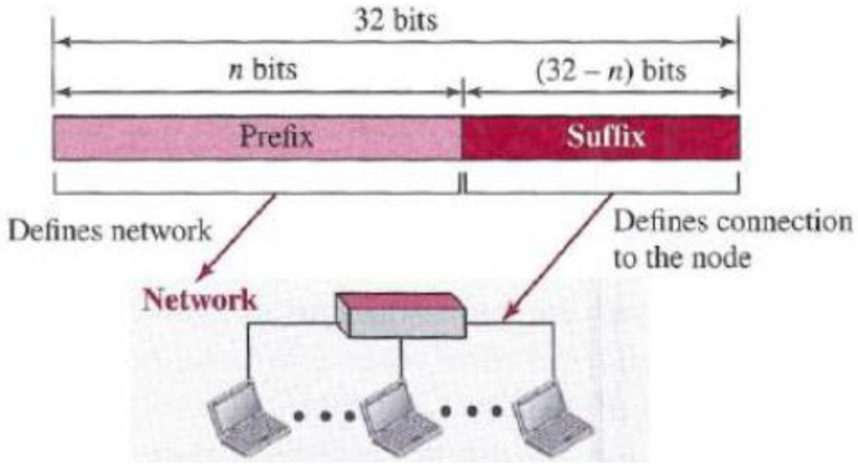
An Example



Total Length
Identification
4020
14,567
0
000
offset
Bytes 0000–3999
Original datagram
Do not fragment
1420
14,567
1
000
offset
Bytes 0000–1399
F 1
1420
14,567
1
175
offset
Bytes 1400–2799
F 2
1220
14,567
0
350
offset
Bytes 2800–3999
F 3
More
Offset= starting byte/8=1400/8
820
14,567
1
175
offset
Bytes 1400–2199
F 2.1
620
14,567
1
275
offset
Bytes 2200–2799
F 2.2

IP Addressing

- IP Address:
  - 32 bits used to represent IPv4
  - E.g., 192.19.241.18 in **dotted decimal notation**

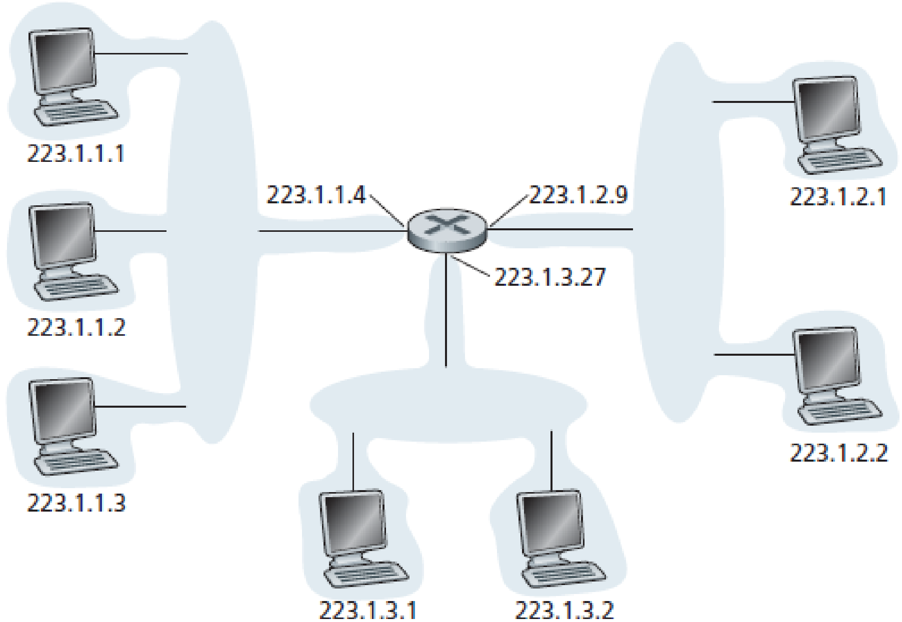


- Total address space: 2^n for *n* bit address
  - Last address: 255.255.255.255 if n=32

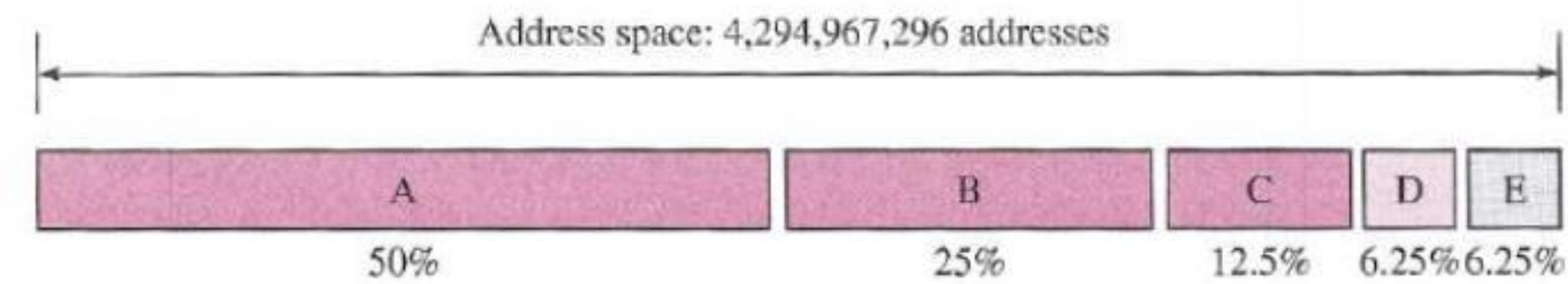
- An IP address is technically associated with an interface, rather than with the host or router containing that interface

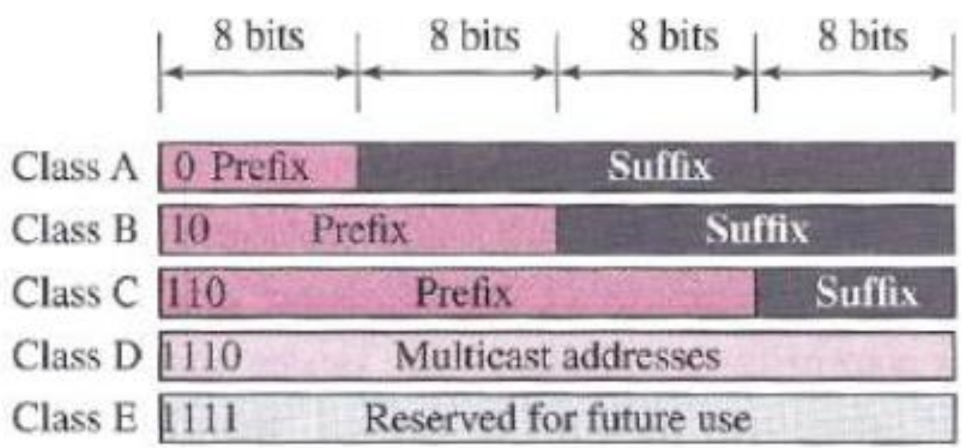
- The boundary between the host/router and the physical link is called an **interface**.

- Each interface in the global Internet must have an IP address that is **globally unique** (except behind NAT)



Classful Addressing





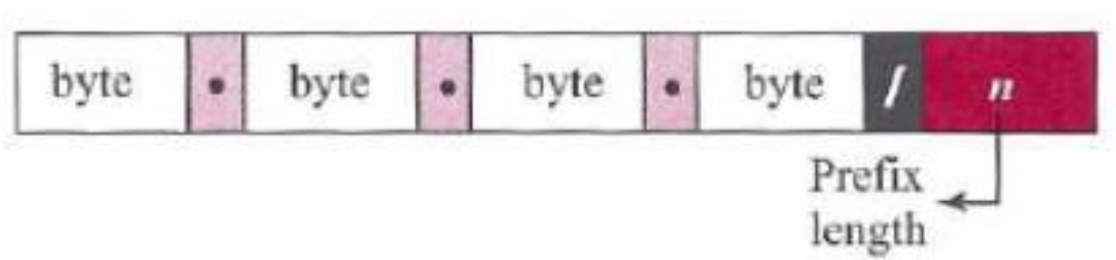
Class	Prefixes	First byte
A	$n = 8$ bits	0 to 127
B	$n = 16$ bits	128 to 191
C	$n = 24$ bits	192 to 223
D	Not applicable	224 to 239
E	Not applicable	240 to 255

Problem and Solution

- Problem in Classful Addressing: **Address Depletion**

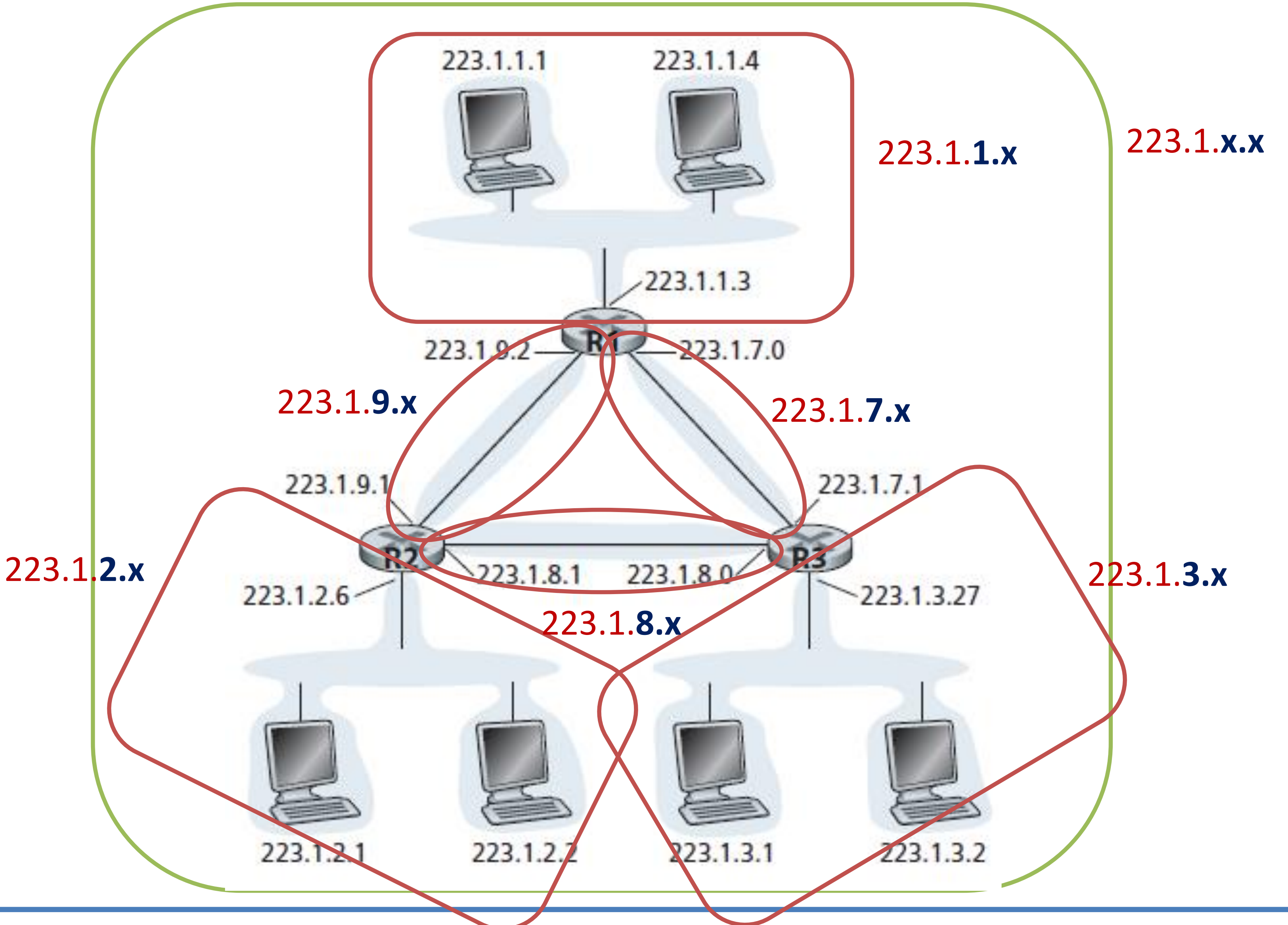
- Solution:
  - Subnetting: a larger block of address is divided into several subnets
  - Supernetting: several smaller blocks of addresses are combined to make a larger block

- Better Solution:
  - Classless addressing: variable length blocks that belong to no classes; uses slash notation to identify prefix length

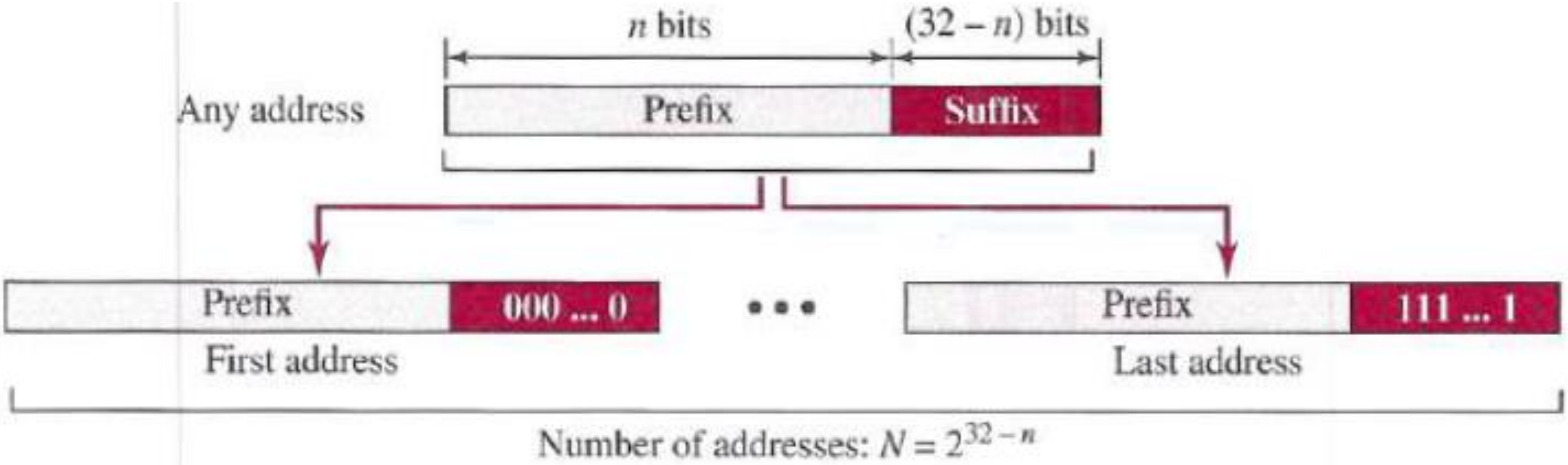


Examples:
12.24.76.8/**8**
23.14.67.92/**12**
220.8.24.255/**25**

Example of Six Subnets



Extract block from an Address



Let an address: 167.199.170.82/27 . . .01010010

Number of Address: $2^{(32-27)} = 32$

First Address: 167.199.170.64/27 . . .01000000

Last Address: 167.199.170.95/27 . . .01011111

Address Mask

It is a 32-bit number in which the *n* leftmost bits are set to 1s and the rest of the bits (*32 - n*) are set to 0s.

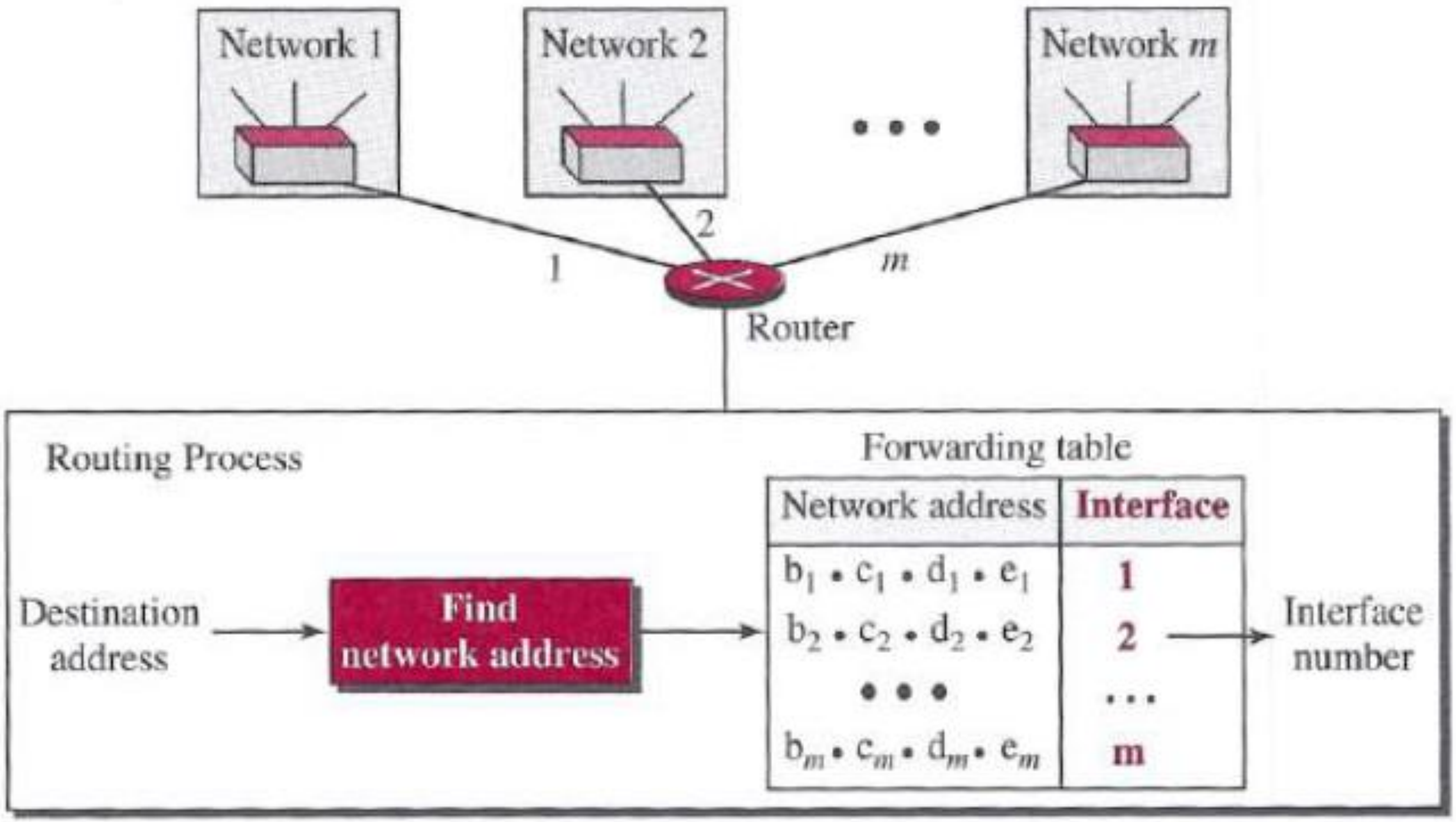
It can be used by a computer program to extract the information in a block, using the three bit-wise operations NOT, AND, and OR.

Given address:	167.199.170.82/27	. . .01010010
Mask:	255.255.255.224	. . .11100000

Number of address in the block: NOT (mask) + 1 = 31+1 = 32

First Address: (address) AND (mask)	167.199.170.64	(01000000)
Last Address: (address) OR (NOT (mask))	167.199.170.95	(01011111)

Network Address



- Network address is the first address of the block

Block Allocation

- Internet Corporation for Assigned Names and Numbers (ICANN) is the global authority.
- ICANN assigns a large block of address to ISP
- ISP assigns individual IP to stations/ small block to an organization
- Rules:
  1. The number of requested addresses, *N,* needs to be a power of 2. (as, $N=2^{32-n} \Rightarrow n = 32 - \log_2 N$)
  2. The allocated first address needs to be divisible by the number of addresses in the block. (for contiguous address)

- More levels of hierarchy can be created using subnetting.
- Rules:
  1. The number of addresses (N) in each subnetwork should be a power of 2; i.e., $N = 2^k$
  2. The prefix length (in bits) for each subnetwork should be found using the following formula:
     $n_{subnet} = 32 - \log_2 N$
  3. The starting address in each subnetwork should be divisible by the number of addresses in that subnetwork. (i.e., *least significant k bits* ***should all be 0)***

Example

- An organization is granted a block of addresses with the beginning address 14.24.74.0/24.
- The organization needs to have 3 sub-blocks of addresses to use in its three subnets: one sub-block of 10 addresses, one sub-block of 60 addresses, and one sub-block of 120 addresses. Design the sub-blocks.

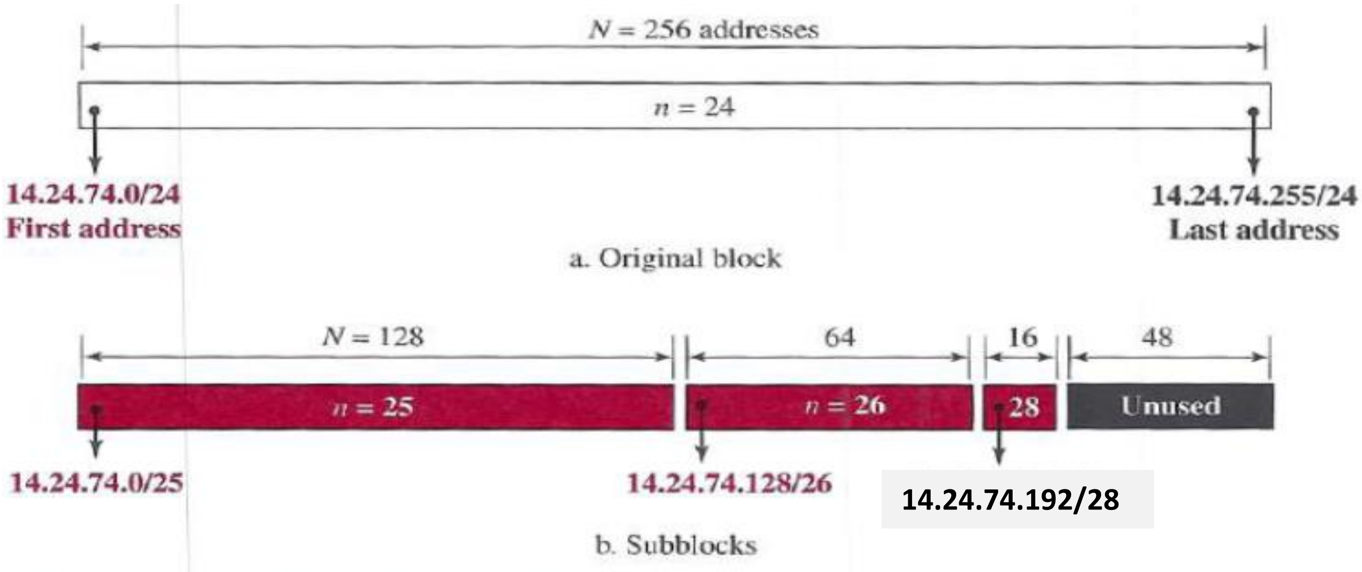
- Solution: Allocated no. of address: $2^{32-24} = 256$
  First address: 14.24.74.0/24; Last address: 14.24.74.255/24
  Mask: 255.255.255.0

  We should start with largest sub-blocks.
  - $N_1=120 \Rightarrow N_1=128 \Rightarrow n_1=32-\log_2 128 = 25$
    First address: 14.24.74.0/25
    Last address: 14.24.74.127/25 Mask: 255.255.255.128 (as last octet: 1000 0000)

  - $N_2=60 \Rightarrow N_2=64 \Rightarrow n_2=32-\log_2 64 = 26$
    First address: 14.24.74.128/26
    Last address: 14.24.74.191/26 Mask: 255.255.255.192 (as last octet: 1100 0000)

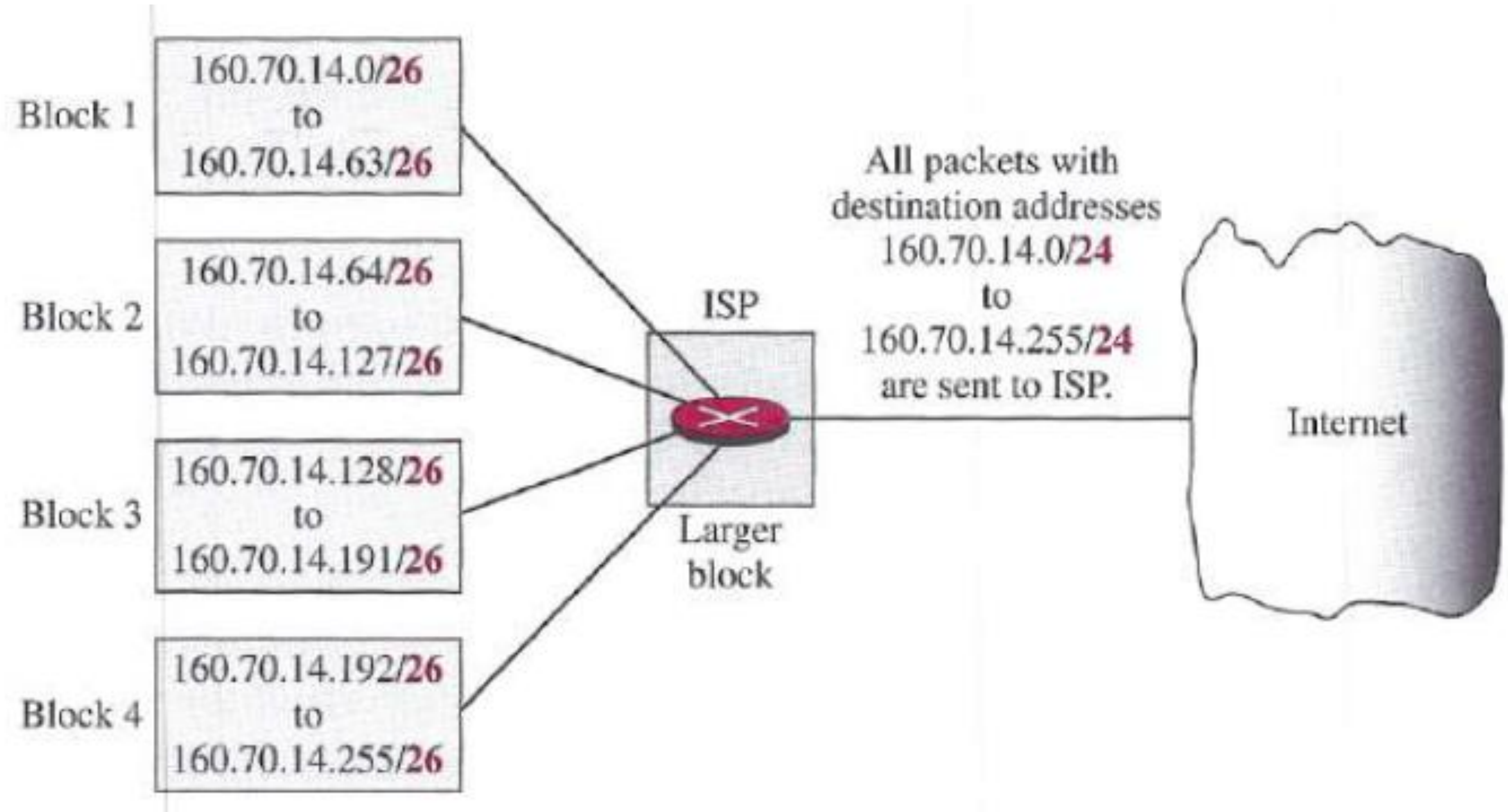
  - $N_3=10 \Rightarrow N_3=16 \Rightarrow n_3=32-\log_2 16 = 28$
    First address: 14.24.74.192/28
    Last address: 14.24.74.207/28 Mask: 255.255.255.240 (as last octet: 1111 0000)

Cont…



- Example: Let destination IP of a packet 14.24.74.195
  So, Network Address= (14.24.74.195) AND (255.255.255.0) = 14.24.74.0
- Subnet 3: (14.24.74.195) AND (255.255.255.240) = . . . (1100 0011 AND 1111 0000) = 14.24.74.192
  => Correct
- Subnet 2: (14.24.74.195) AND (255.255.255.192) = . . . (1100 0011 AND 1100 0000) = 14.24.74.192
  => Not Correct
- Subnet 1: (14.24.74.195) AND (255.255.255.128) = . . . (1100 0011 AND 1000 0000) = 14.24.74.128
  => Not correct

Address Aggregation

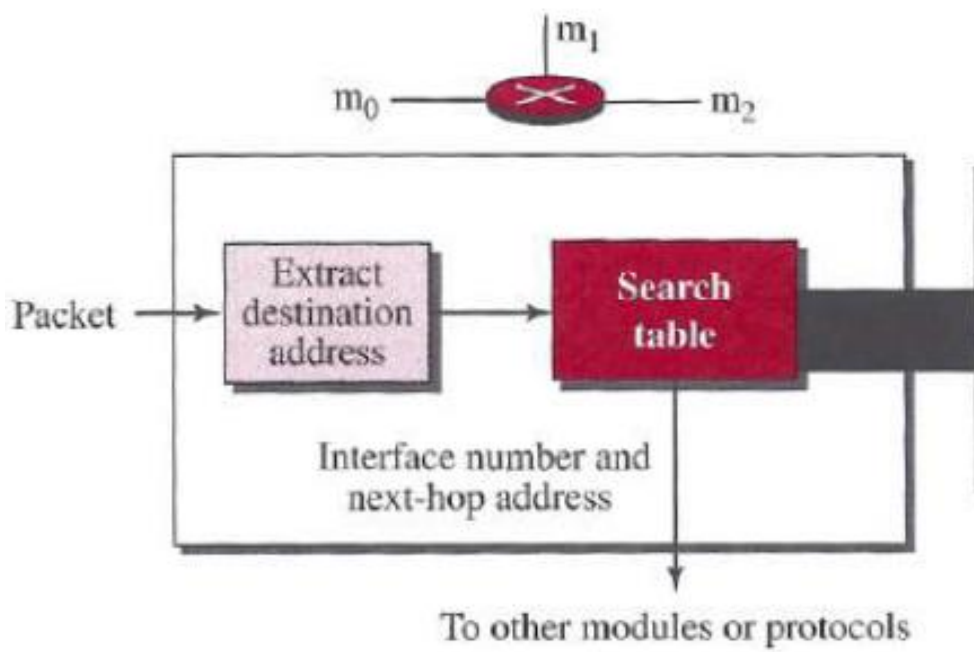


Special Addresses

- ***This-host Address:*** 0.0.0.0/32
  - It is used whenever a host needs to send an IP datagram but it does not know its own address to use as the source address.
- ***Limited-broadcast Address:*** 255.255.255.255/32
  - It is used whenever a router or a host needs to send a datagram to all devices in a network.
- ***Loopback Address:*** 127.0.0.0/8
  - Any address in the block is used to test a piece of software in the machine.
- ***Private Addresses:*** (these are used in NAT)
  - 10.0.0.0/8
  - 172.16.0.0/12
  - 192.168.0.0/16
  - 169.254.0.0/16
- ***Multicast Addresses:*** *224.0.0.0/4*
  - Reserved for multicast

IP Packet Forwarding

- **Two Approaches**:
  - Based on Destination IP
    - For connectionless protocol
  - Based on Label
    - For connection oriented protocol



Forwarding table

Network address including mask	Next-hop IP address	Interface
$x_0.y_0.z_0.t_0/n_0$	....	m_0
$x_1.y_1.z_1.t_1/n_1$	....	m_1
$x_2.y_2.z_2.t_2/n_1$	....	m_2

Forwarding (by Dest. IP)

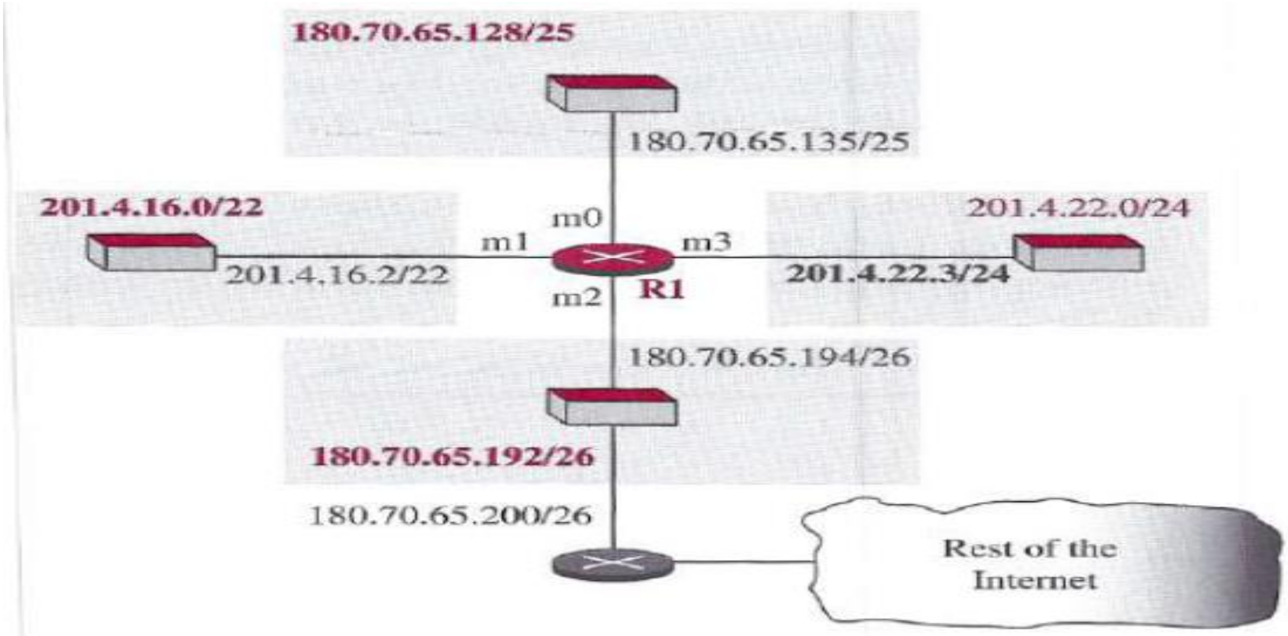
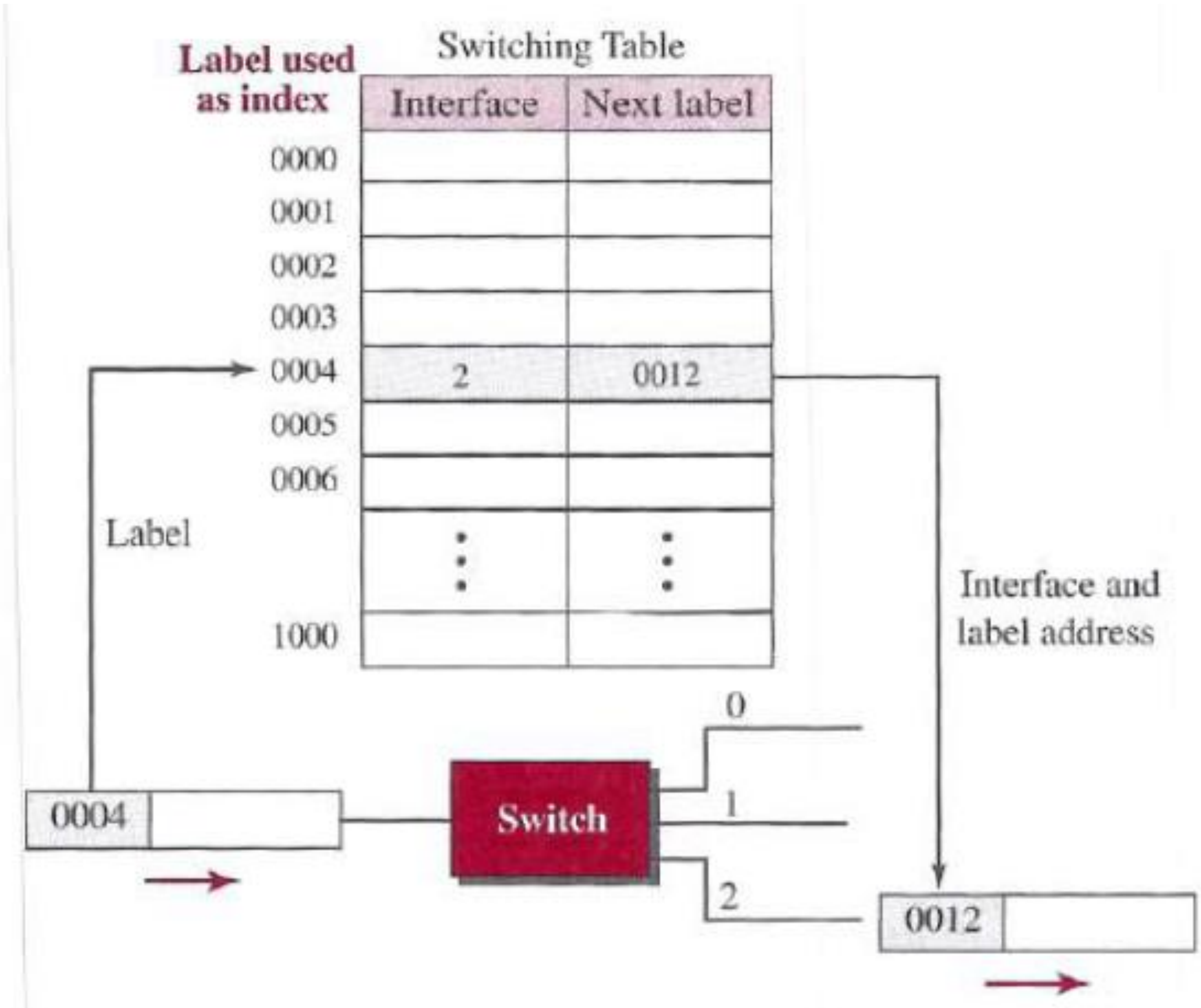


Table for Router R1

Network address/mask	*Next hop*	*Interface*
180.70.65.192/**26**	—	m2
180.70.65.128/**25**	—	m0
201.4.22.0/**24**	—	m3
201.4.16.0/**22**	—	m1
Default	180.70.65.200	m2

Forwarding (by Label)



Thanks!