CMSC417

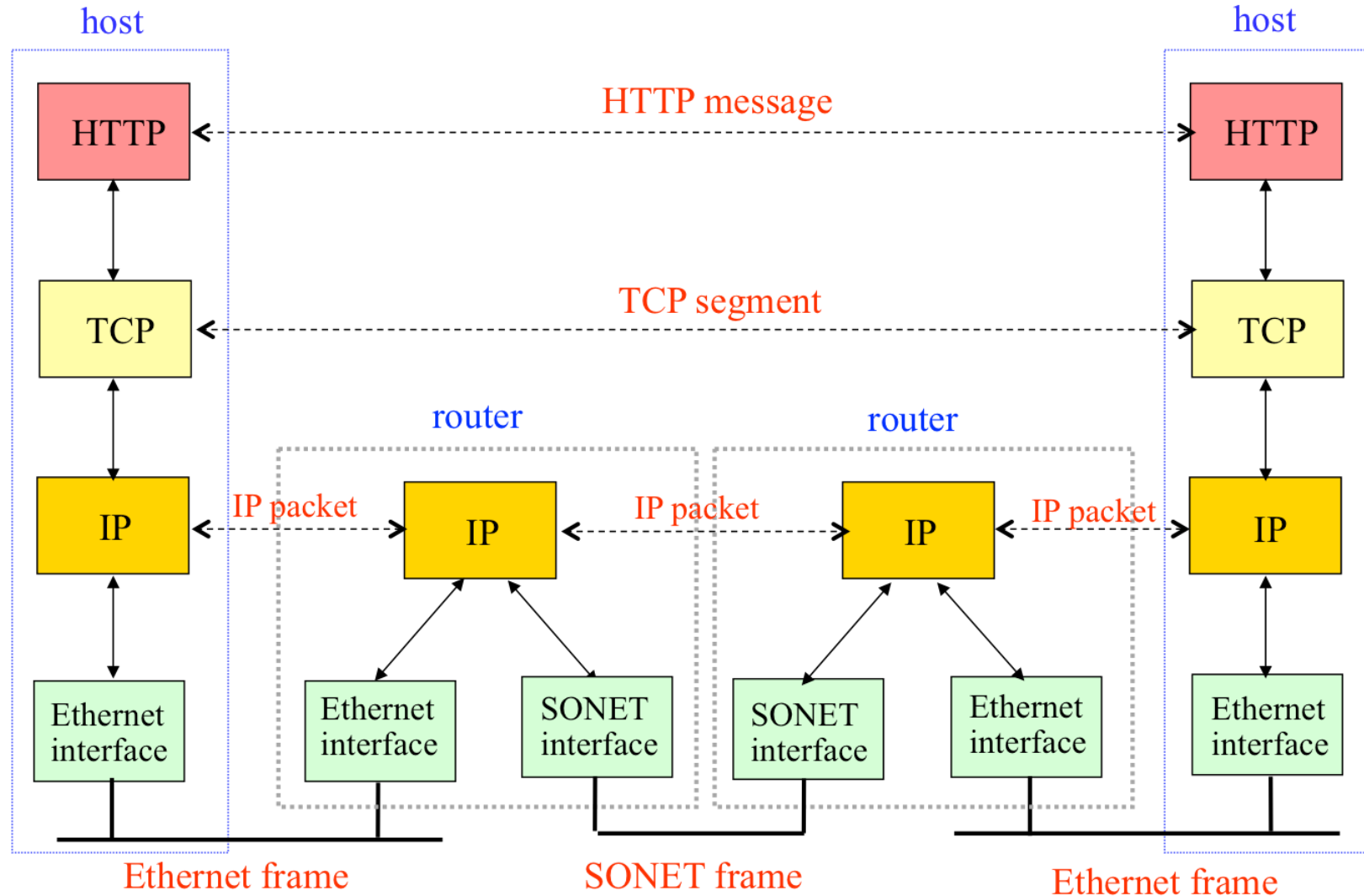# **Computer Networks**
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Message, Segment, Packet, and Frame

HTTP message

TCP segment

IP packet

IP packet

IP packet

host

host

router

router

HTTP

TCP

IP

Ethernet interface

Ethernet interface

SONET interface

SONET interface

Ethernet interface

IP

IP

HTTP

TCP

IP

Ethernet interface

Ethernet frame

SONET frame

Ethernet frame

Quality of Service

- Application requirements
- Traffic shaping
- Packet scheduling
- Admission control
- Integrated services
- Differentiated services

Application Requirements (1)

Different applications care about different properties

- We want all applications to get what they need

.

Application	Bandwidth	Delay	Jitter	Loss
Email	Low	Low	Low	Medium
File sharing	High	Low	Low	Medium
Web access	Medium	Medium	Low	Medium
Remote login	Low	Medium	Medium	Medium
Audio on demand	Low	Low	High	Low
Video on demand	High	Low	High	Low
Telephony	Low	High	High	Low
Videoconferencing	High	High	High	Low

"High" means a demanding requirement, e.g., low delay

Application Requirements (2)

Network provides service with different kinds of QoS
(Quality of Service) to meet application requirements

Network Service	Application
Constant bit rate	Telephony
Real-time variable bit rate	Videoconferencing
Non-real-time variable bit rate	Streaming a movie
Available bit rate	File transfer

Example of QoS categories from ATM networks

Categories of QoS and Examples

1. Constant bit rate
   - Telephony

2. Real-time variable bit rate
   - Compressed videoconferencing

3. Non-real-time variable bit rate
   - Watching a movie on demand

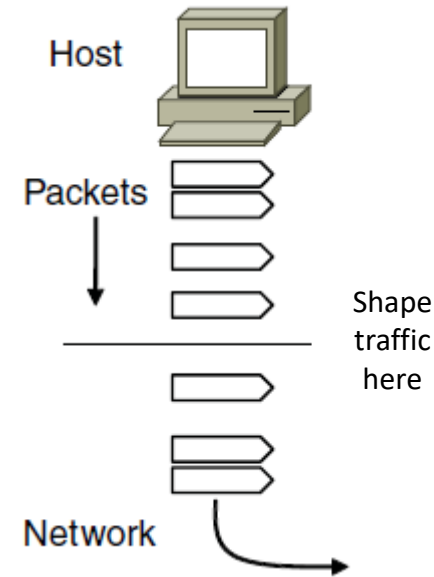4. Available bit rate
   - File transfer

Buffering

Smoothing the output stream by buffering packets.
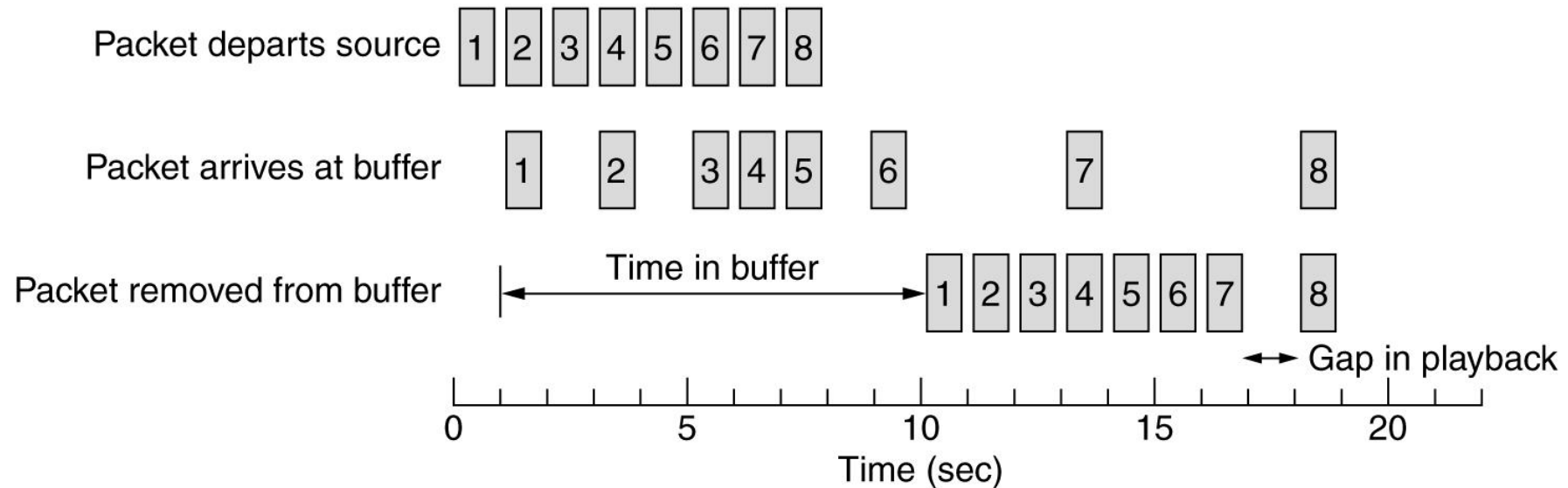
Traffic Shaping (1)

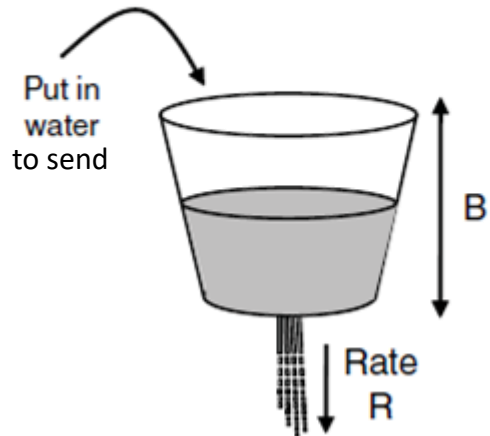Traffic shaping regulates the average rate and burstiness of data entering the network

- Lets us make guarantees
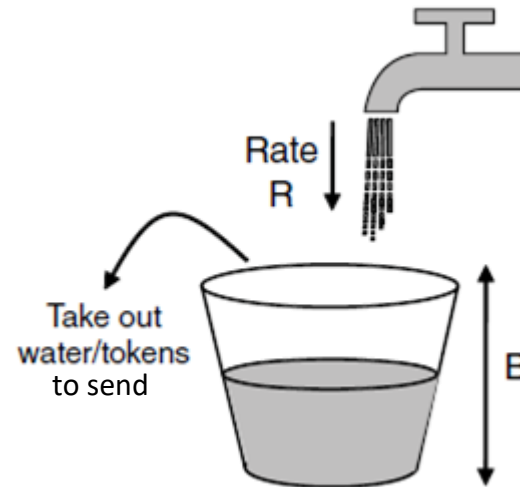

Host

Packets

Shape traffic here

Network

Traffic Shaping (2)

Token/Leaky bucket limits both the average rate (R) and short-term burst (B) of traffic

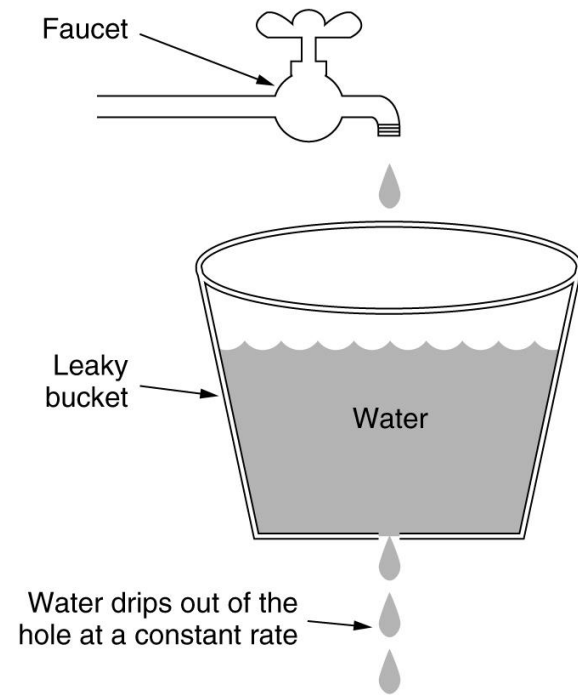- For token, bucket size is B, water enters at rate R and is removed to send; opposite for leaky.
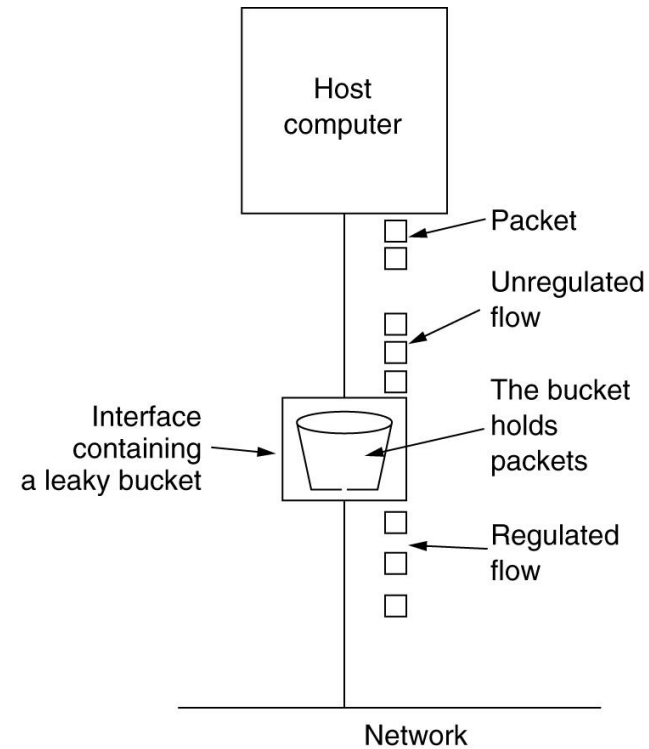

Leaky bucket
(need not full to send)

Token bucket
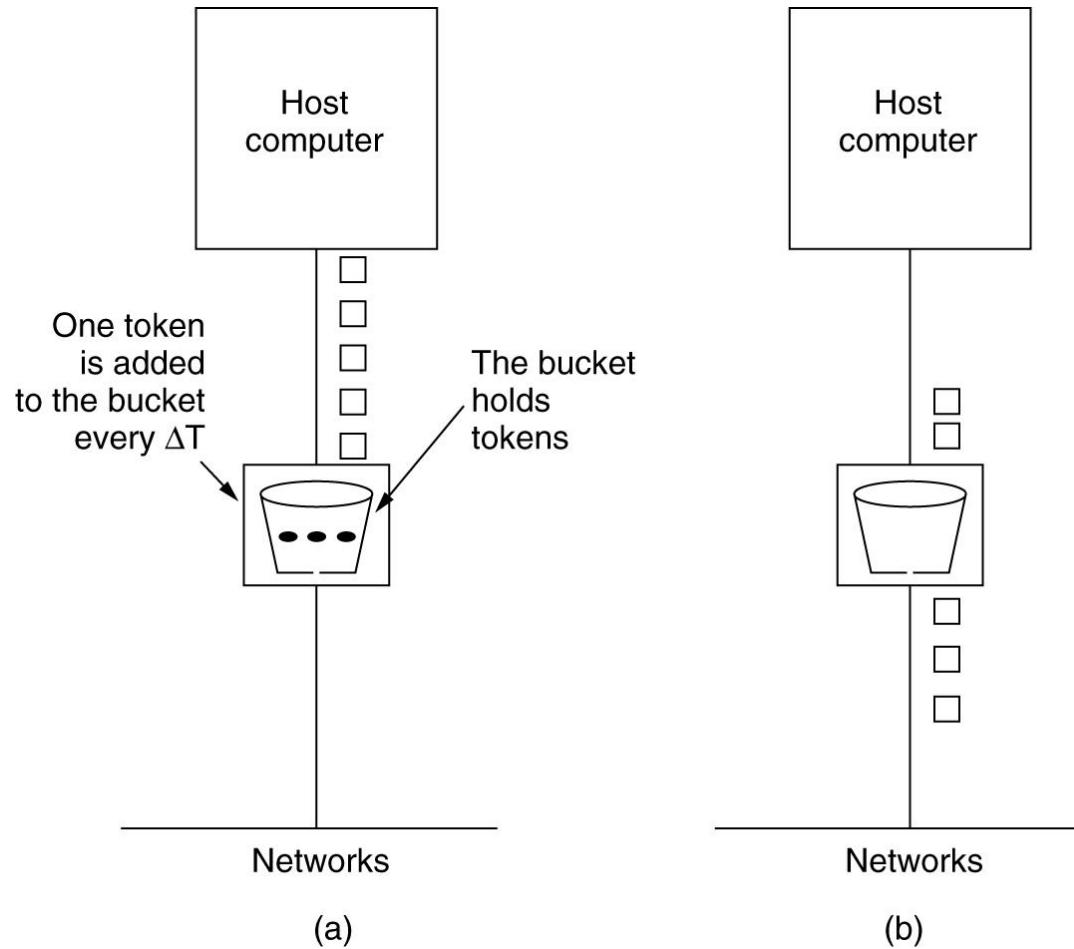(need some water to send)

The Leaky Bucket Algorithm

(a)

(b)

(a) A leaky bucket with water. (b) a leaky bucket with packets.

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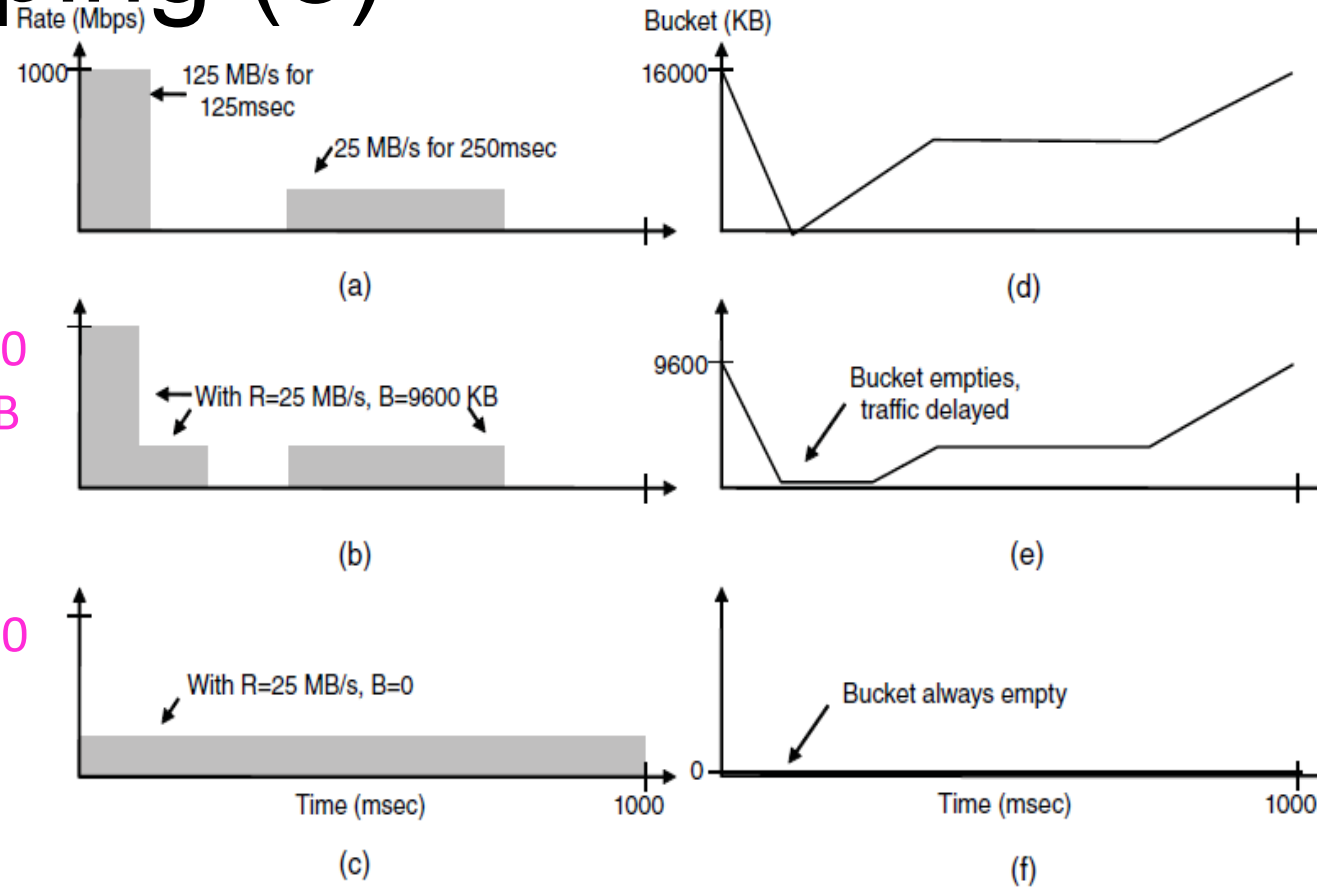# The Token Bucket Algorithm

(a) Before.   (b) After.

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Traffic Shaping (3)

Host traffic
R=200 Mbps
B=16000 KB

↓

Shaped by R=200
Mbps B=9600 KB

↓

Shaped by R=200
Mbps B=0 KB

Rate (Mbps)

1000 — 125 MB/s for 125msec

25 MB/s for 250msec

(a)

With R=25 MB/s, B=9600 KB

(b)

With R=25 MB/s, B=0

Time (msec)   1000

(c)

Bucket (KB)

16000 —

(d)

9600 — Bucket empties, traffic delayed

(e)

Bucket always empty

0 —

Time (msec)   1000

(f)

Smaller bucket size delays traffic and reduces burstiness

Length of Maximum Burst

- Token Bucket
  - Burst Length – *S* seconds
  - Maximum Output Rate – *M* bytes/second
  - Token Bucket Capacity – *B* Bytes
  - Token Arrival Rate – *R* bytes/second
  - Then

$$B + RS = MS \qquad S = \frac{B}{M - R}$$

  - If B = 9600 KB, M = 125 MB/sec, and R = 25 MB/Sec
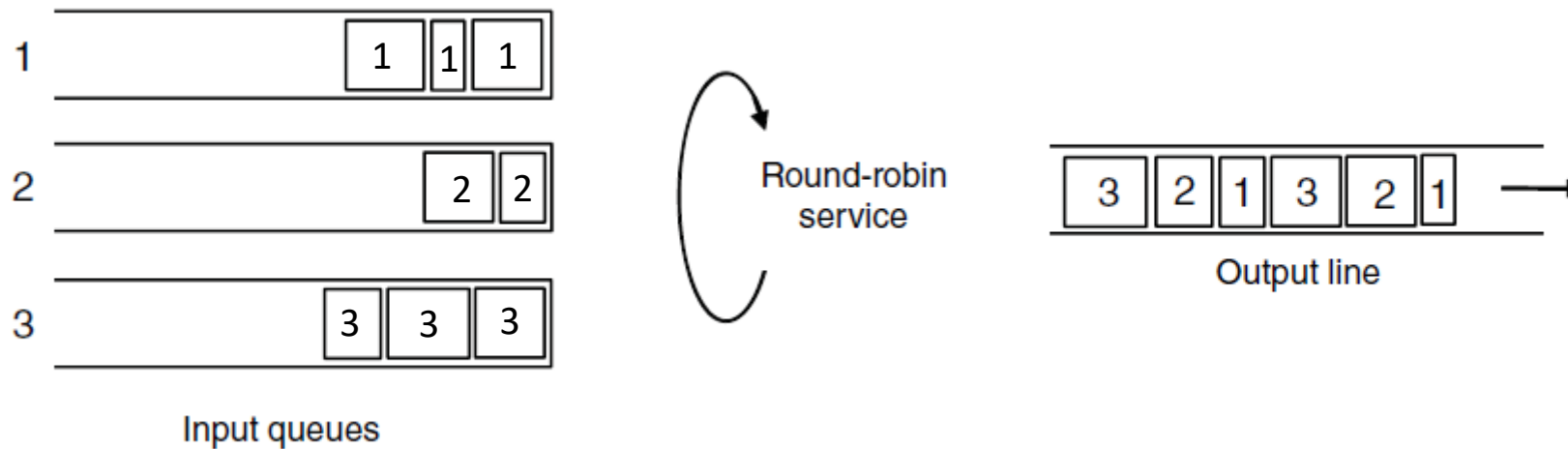
$$s = \frac{9600}{125 - 25} = 96ms$$

Packet Scheduling (1)

Kinds of resources can potentially be reserved for different flows:

1. Bandwidth.

2. Buffer space.

3. CPU cycles.

Packet Scheduling (1)

Packet scheduling divides router/link resources among traffic flows with alternatives to FIFO (First In First Out)
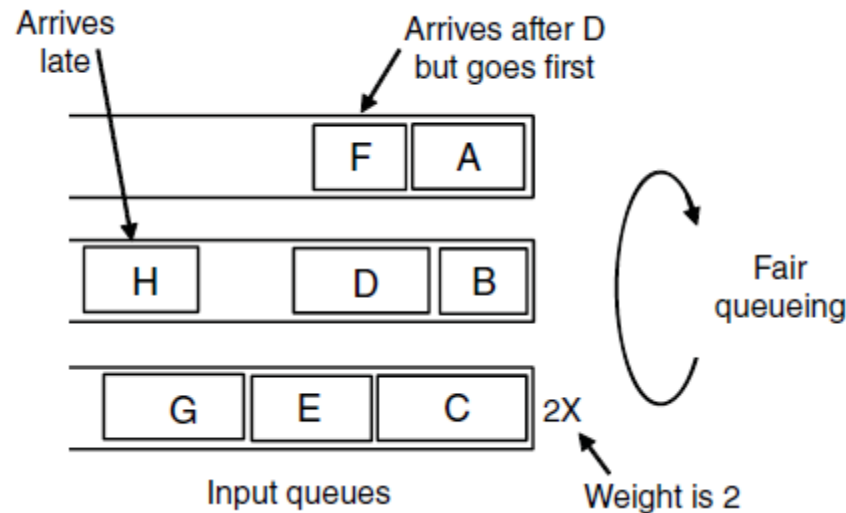

Example of round-robin queuing

Packet Scheduling (2)

Fair Queueing approximates bit-level fairness with different packet sizes; weights change target levels

- Result is WFQ (Weighted Fair Queueing)

Packet	Arrival time	Length	Finish time	Output order
A	0	8	8	1
B	5	6	11	3
C	5	10	10	2
D	8	9	20	7
E	8	8	14	4
F	10	6	16	5
G	11	10	19	6
H	20	8	28	8

$$F_i = max(A_i, F_{i-1}) + L_i/W$$

Packets may be sent out of arrival order

Finish virtual times determine transmission order

Admission Control (1)

Admission control takes a traffic flow specification
and decides whether the network can carry it

- Sets up packet scheduling to meet QoS

Parameter	Unit
Token bucket rate	Bytes/sec
Token bucket size	Bytes
Peak data rate	Bytes/sec
Minimum packet size	Bytes
Maximum packet size	Bytes

Example flow specification

Admission Control (2)

Construction to guarantee bandwidth B and delay D:

- Shape traffic source to a (R, B) token bucket
- Run WFQ with weight W / all weights > R/capacity
- Holds for all traffic patterns, all topologies

$$R < \frac{W \times C}{\sum \text{weights}}$$

(R, B) Traffic source

Router

Capacity C

Weighted fair queue
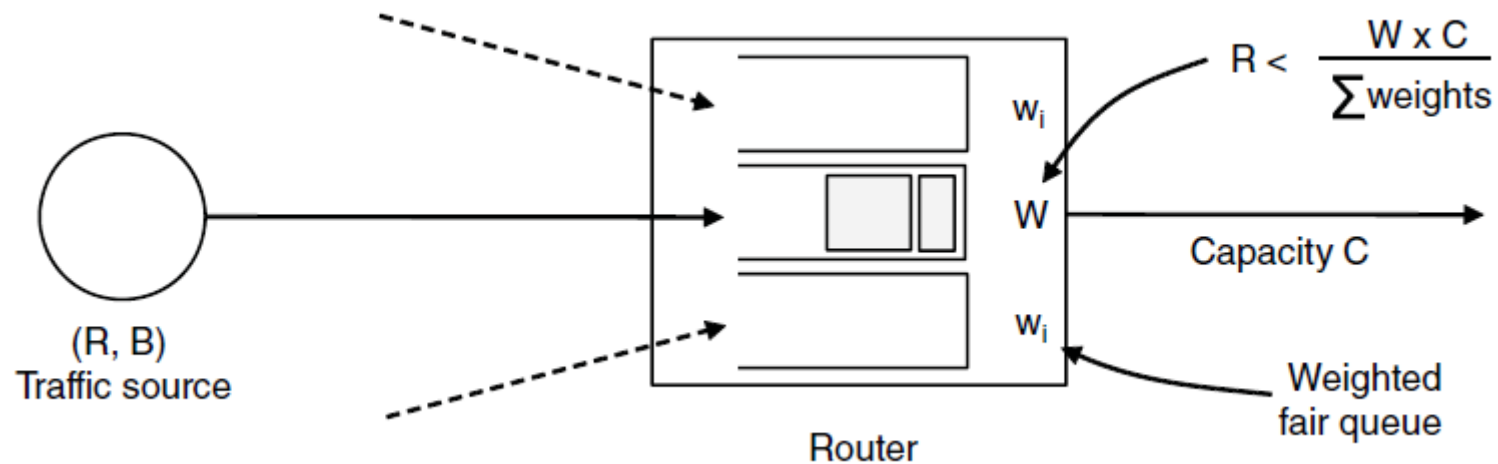
Integrated Services (1)

Design with QoS for each flow; handles multicast traffic.

Admission with RSVP (Resource reSerVation Protocol):
- Receiver sends a request back to the sender
- Each router along the way reserves resources
- Routers merge multiple requests for same flow
- Entire path is set up, or reservation not made
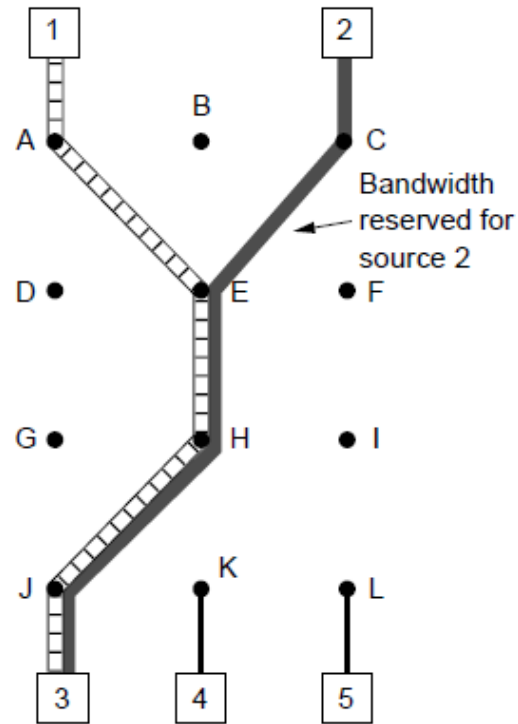
RSVP-The ReSerVation Protocol
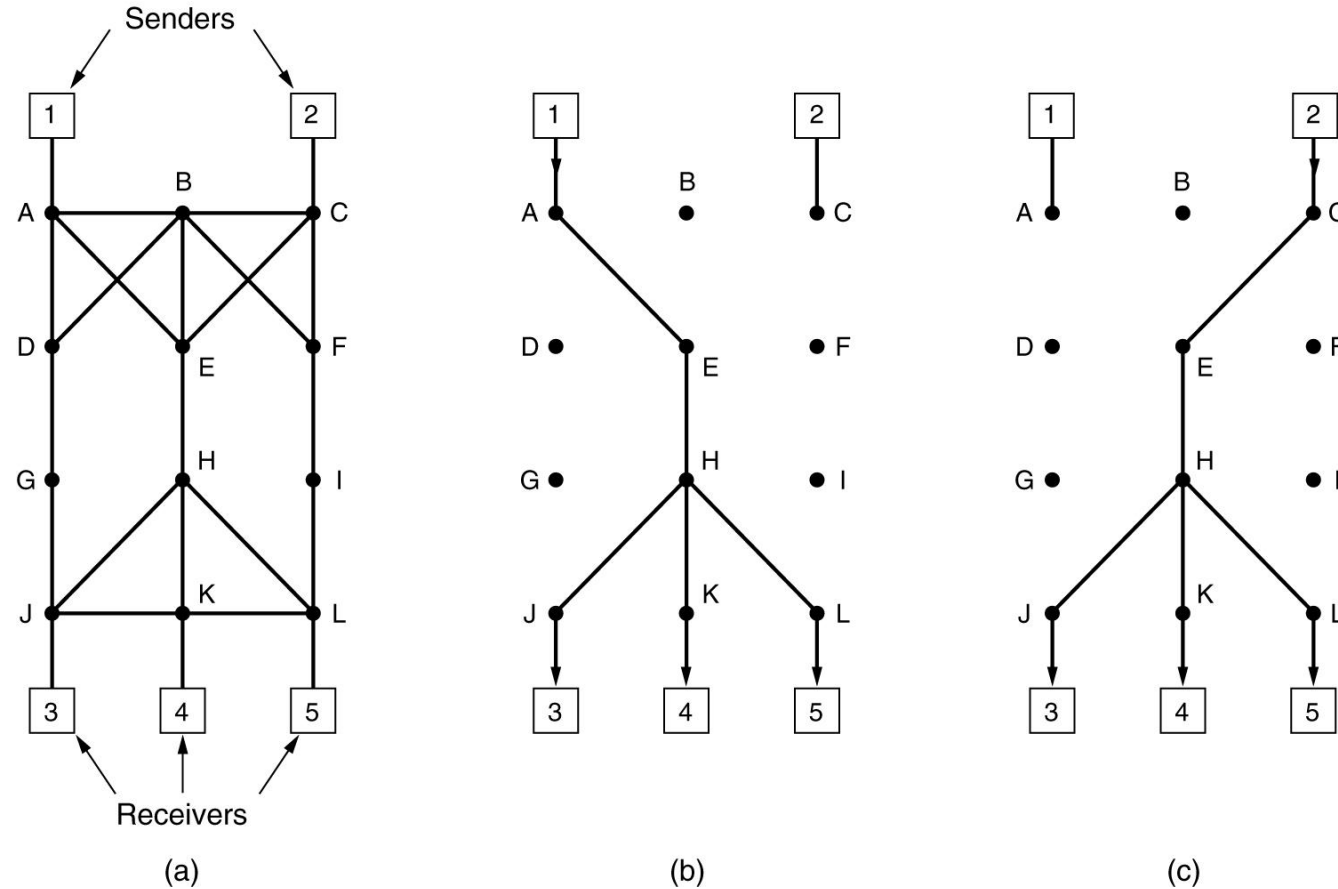
(a) A network, (b) The multicast spanning tree for host 1.
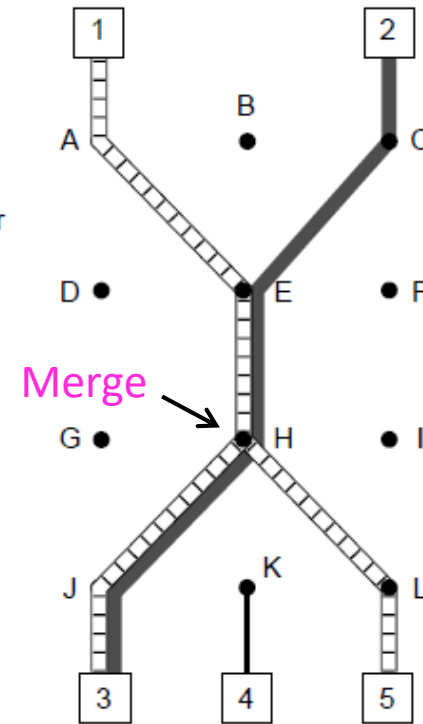(c) The multicast spanning tree for host 2.

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Integrated Services (2)
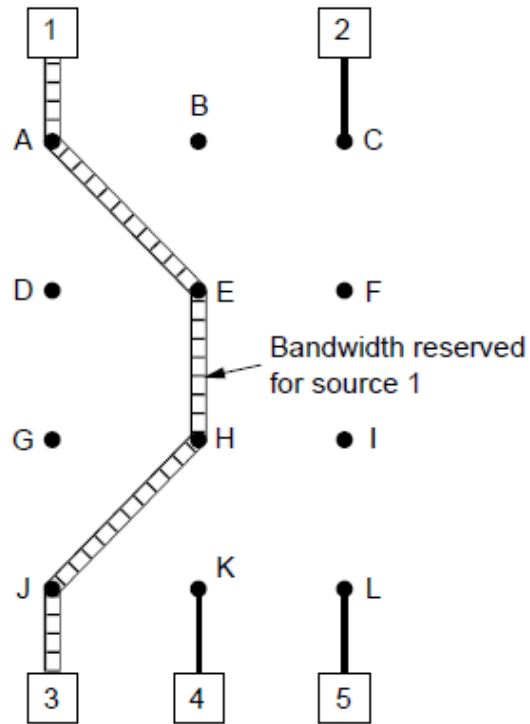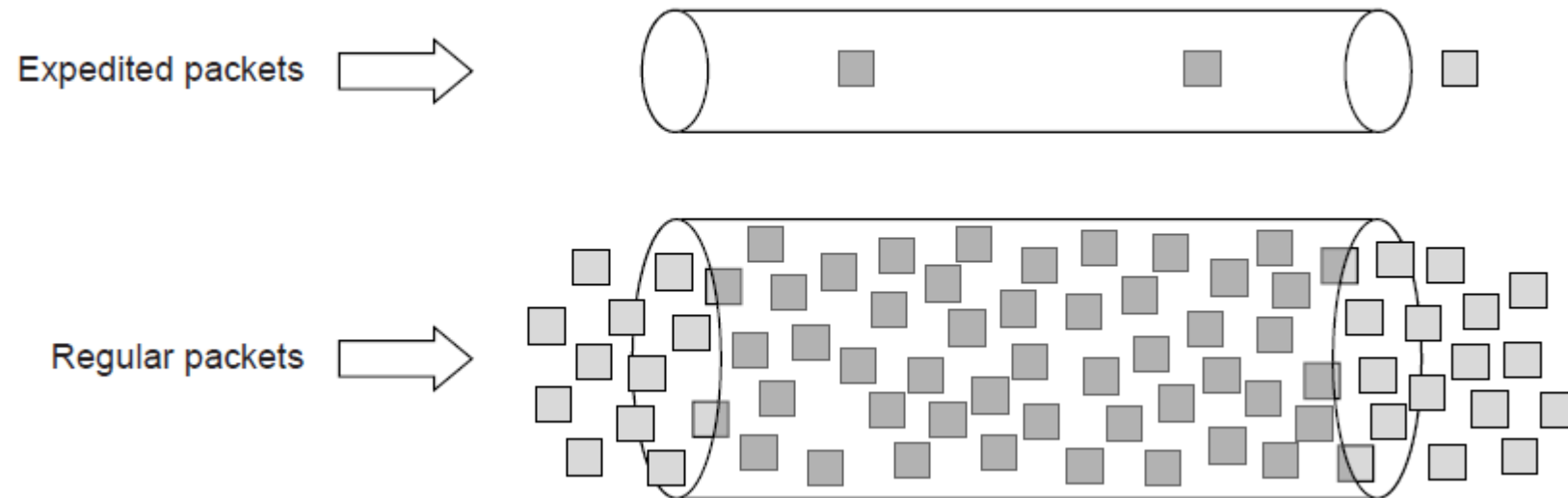

R3 reserves flow from S1

R3 reserves flow from S2

R5 reserves flow from S1; merged with R3 at H

Differentiated Services (1)

- Design with classes of QoS; customers buy what they want
  - Expedited class is sent in preference to regular class
  - Less expedited traffic but better quality for applications

Expedited packets

Regular packets

Assured Forwarding

Implementation of Assured Forwarding:

- Customers mark desired class on packet
- ISP shapes traffic to ensure markings are paid for
- Routers use WFQ to give different service levels
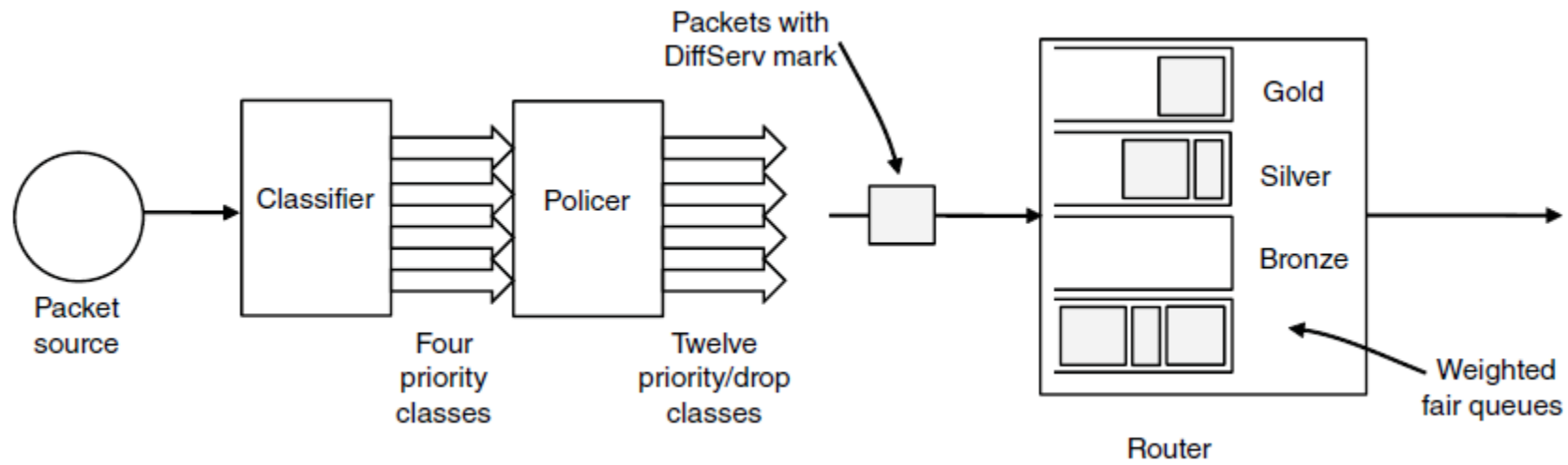
The Network Layer in the Internet

- The IP Protocol
- IP Addresses
- Internet Control Protocols
- OSPF – The Interior Gateway Routing Protocol
- BGP – The Exterior Gateway Routing Protocol
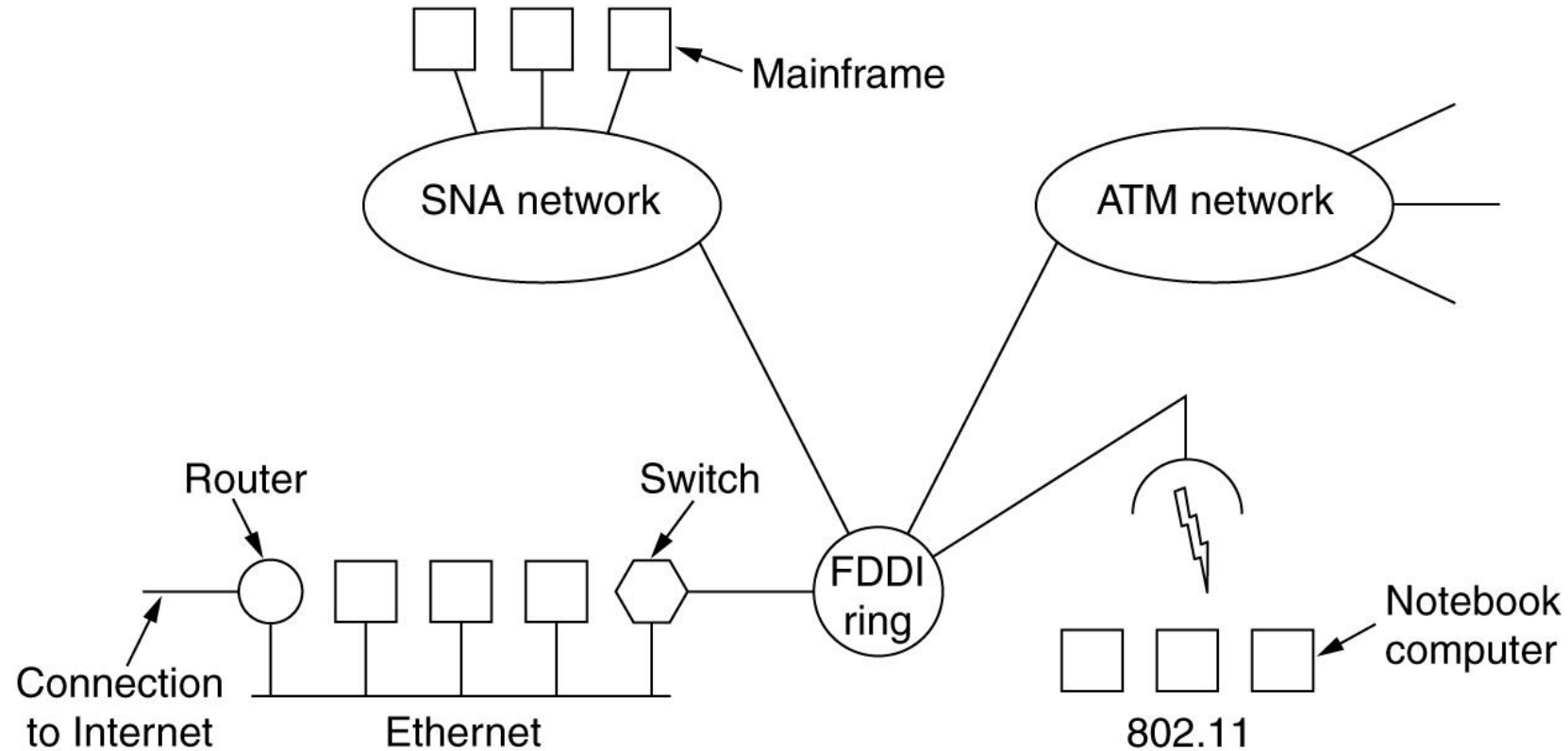- Internet Multicasting
- Mobile IP
- IPv6

Internetworking

Internetworking joins multiple, different networks into a single larger network

- How networks differ »
- How networks can be connected »
- Tunneling »
- Internetwork routing »
- Packet fragmentation »

Connecting Networks

A collection of interconnected networks.

How Networks Differ

| Item	Some Possibilities
Service offered	Connection oriented versus connectionless
Protocols	IP, IPX, SNA, ATM, MPLS, AppleTalk, etc.
Addressing	Flat (802) versus hierarchical (IP)
Multicasting	Present or absent (also broadcasting)
Packet size	Every network has its own maximum
Quality of service	Present or absent; many different kinds
Error handling	Reliable, ordered, and unordered delivery
Flow control	Sliding window, rate control, other, or none
Congestion control	Leaky bucket, token bucket, RED, choke packets, etc.
Security	Privacy rules, encryption, etc.
Parameters	Different timeouts, flow specifications, etc.
Accounting	By connect time, by packet, by byte, or not at all

Some of the many ways networks can differ.

How Networks Can Be Connected

Internetworking based on a common network layer – IP
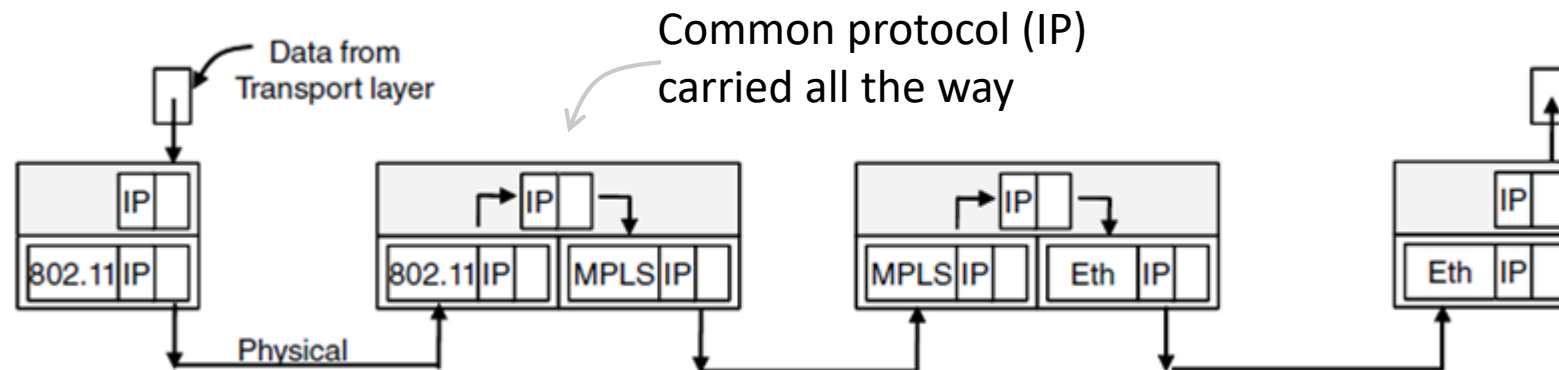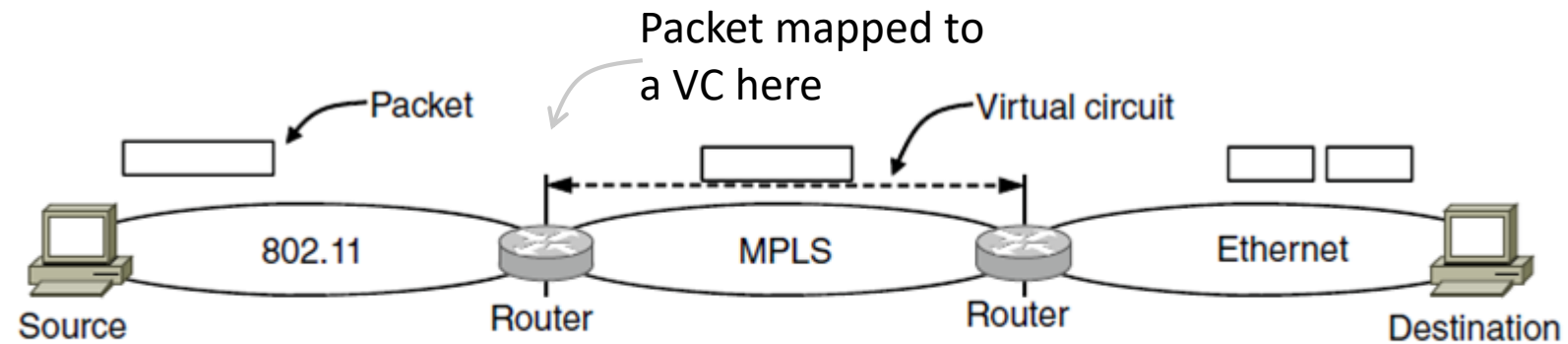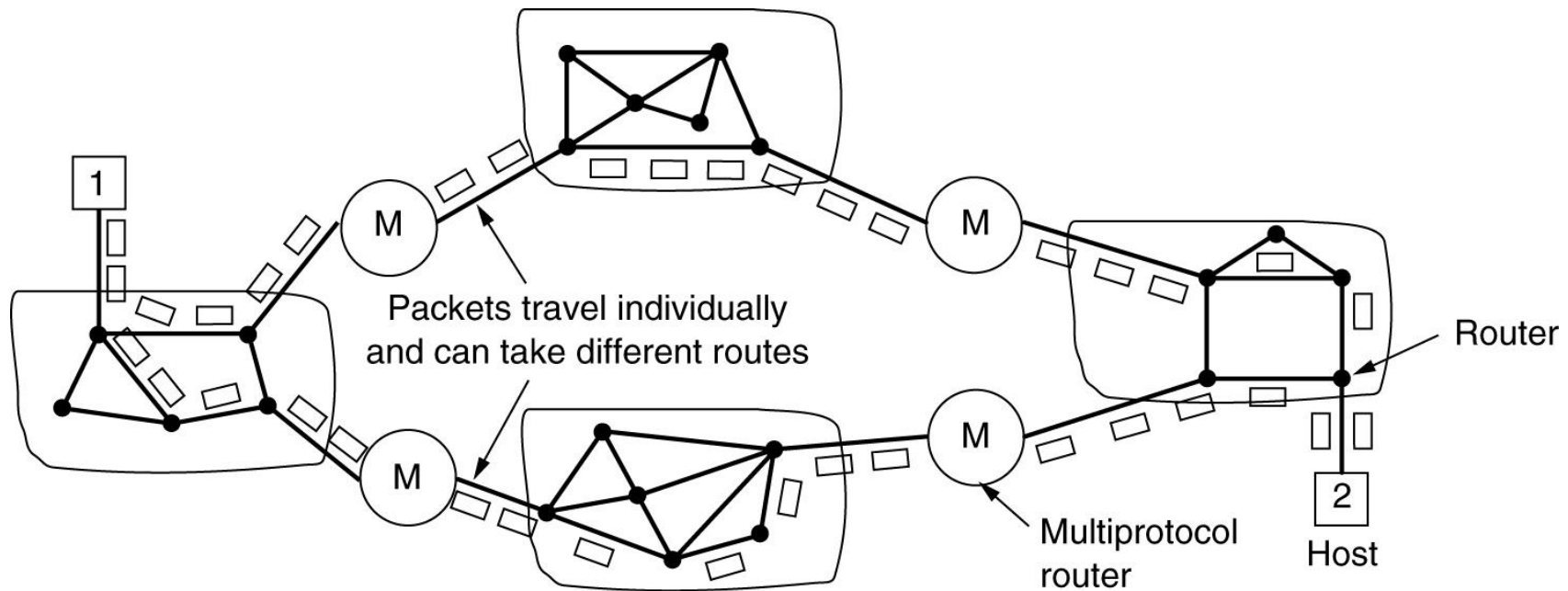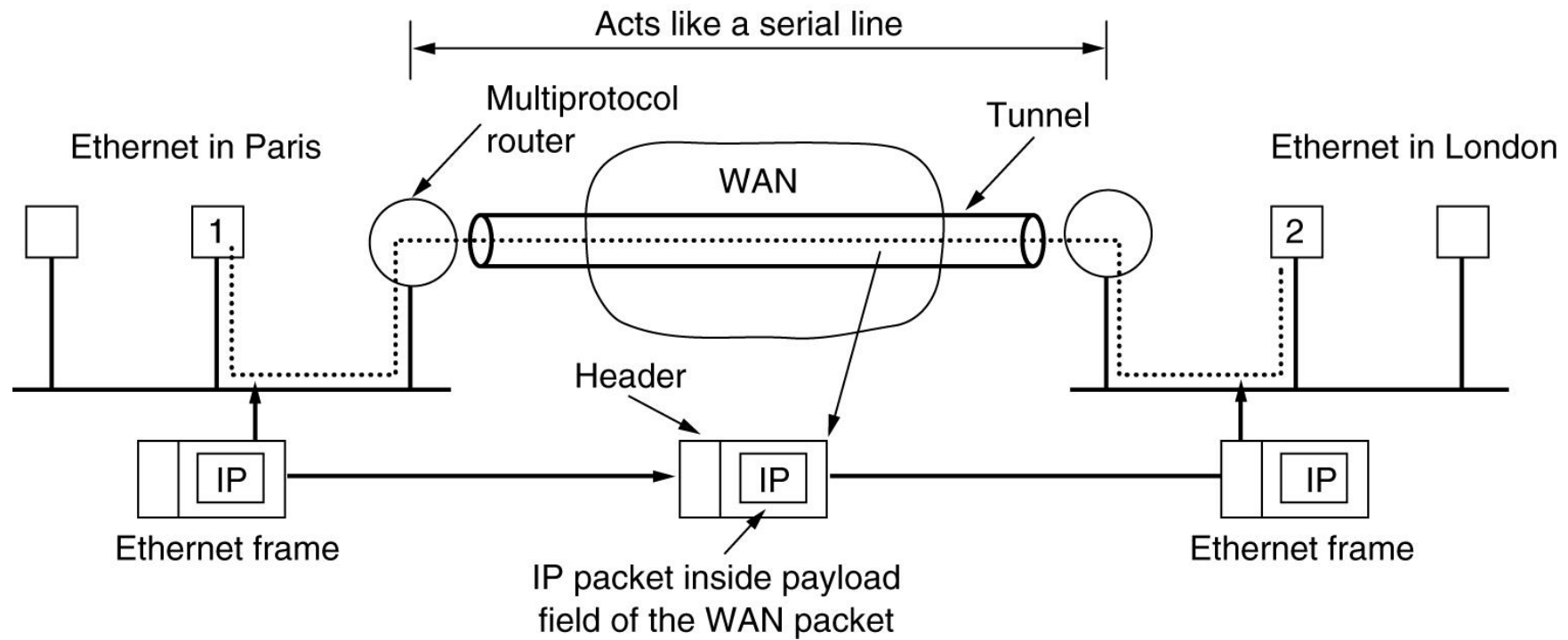
Concatenated Virtual Circuits
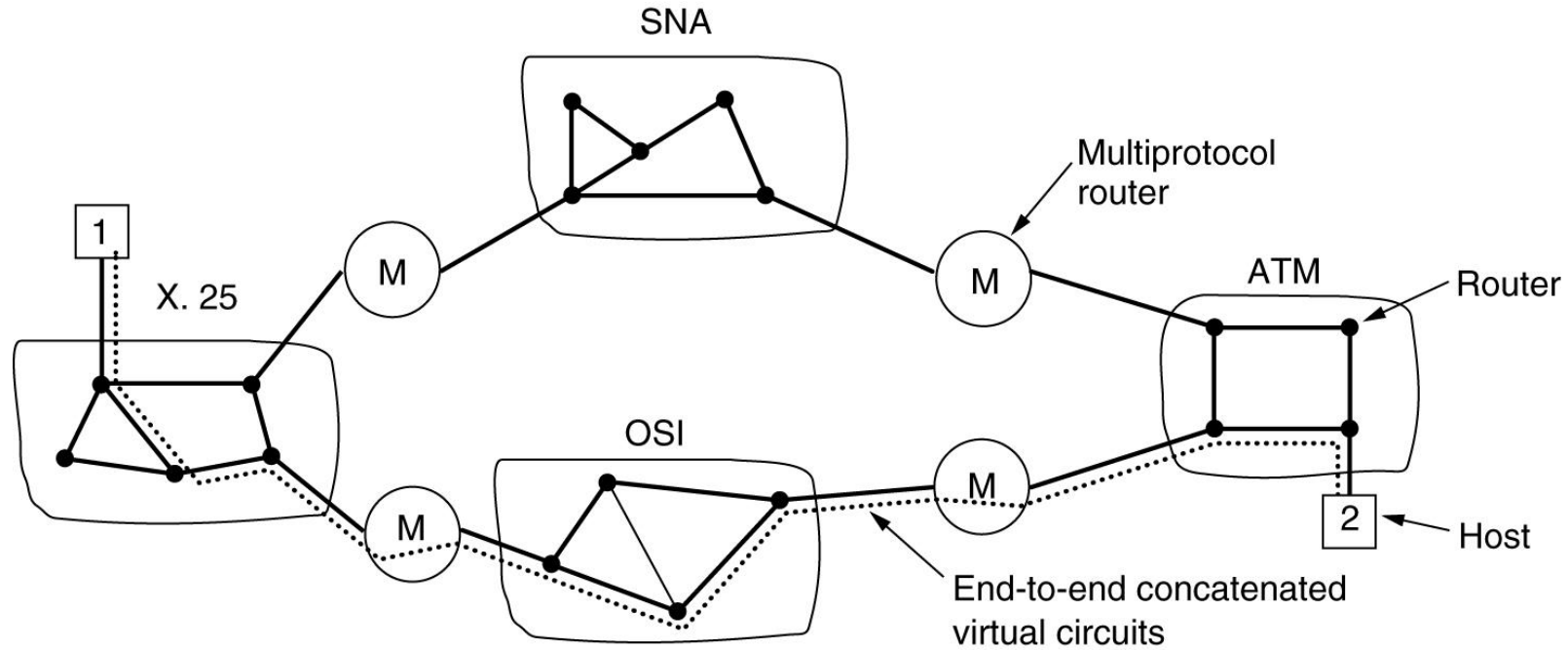
Internetworking using concatenated virtual circuits.

Connectionless Internetworking
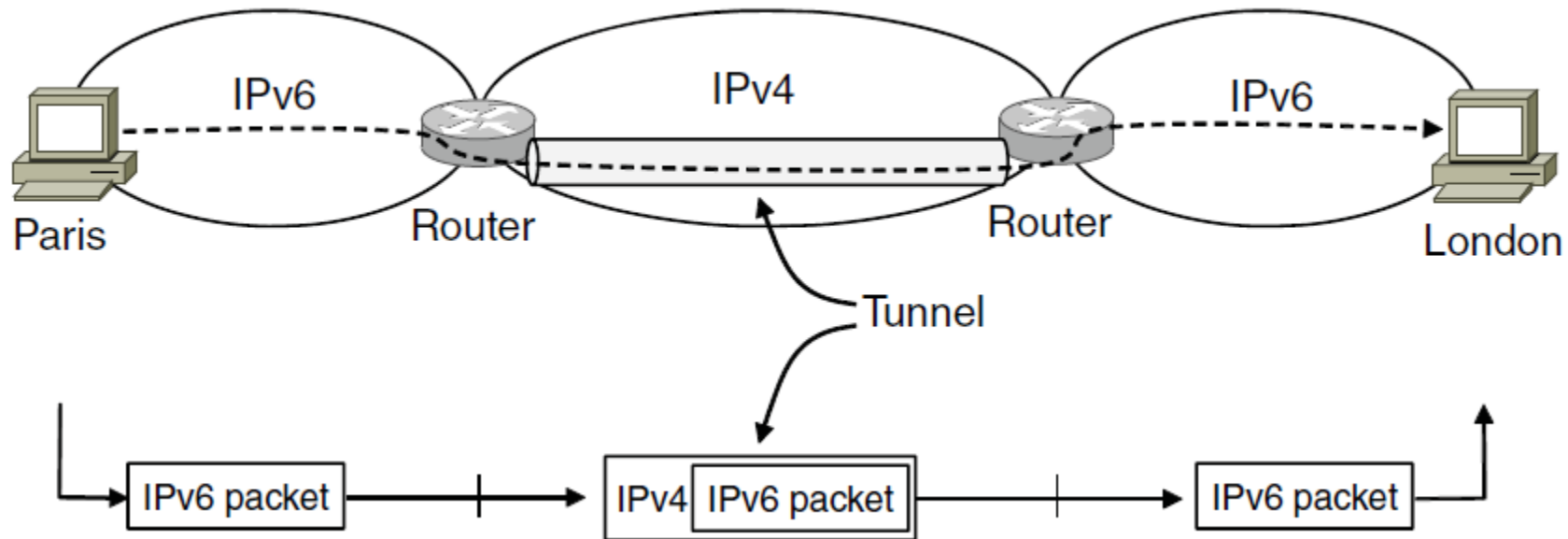

A connectionless internet.

Tunneling

Tunneling (1)

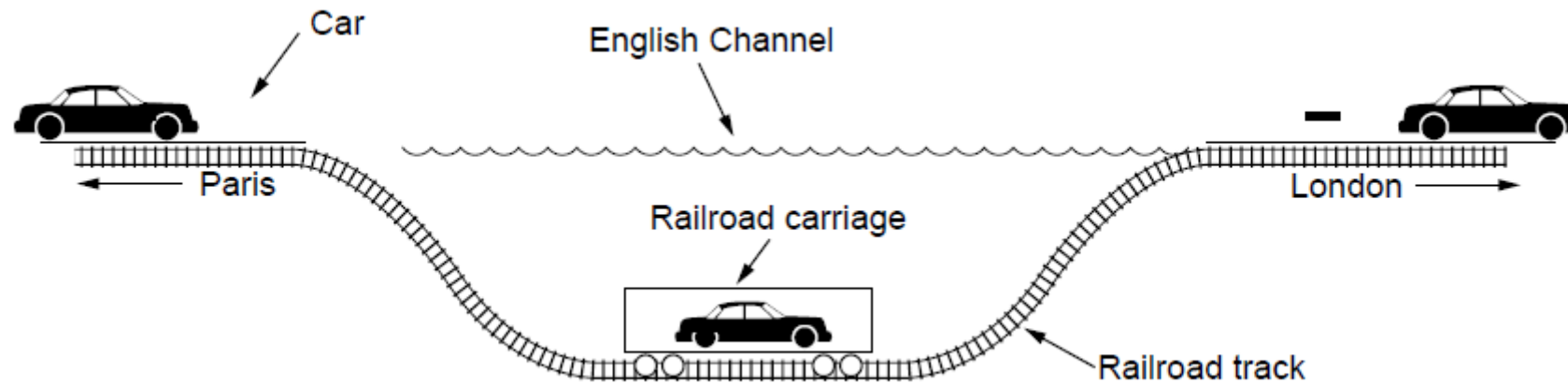Connects two networks through a middle one

- Packets are encapsulates over the middle

Tunneling (2)

Tunneling analogy:

- tunnel is a link; packet can only enter/exit at ends

Network Layer in the Internet (1)

- IP Version 4 »
- Internet Control Protocols »
- Label Switching and MPLS »
- IP Version 6 »
- OSPF—An Interior Gateway Routing Protocol »
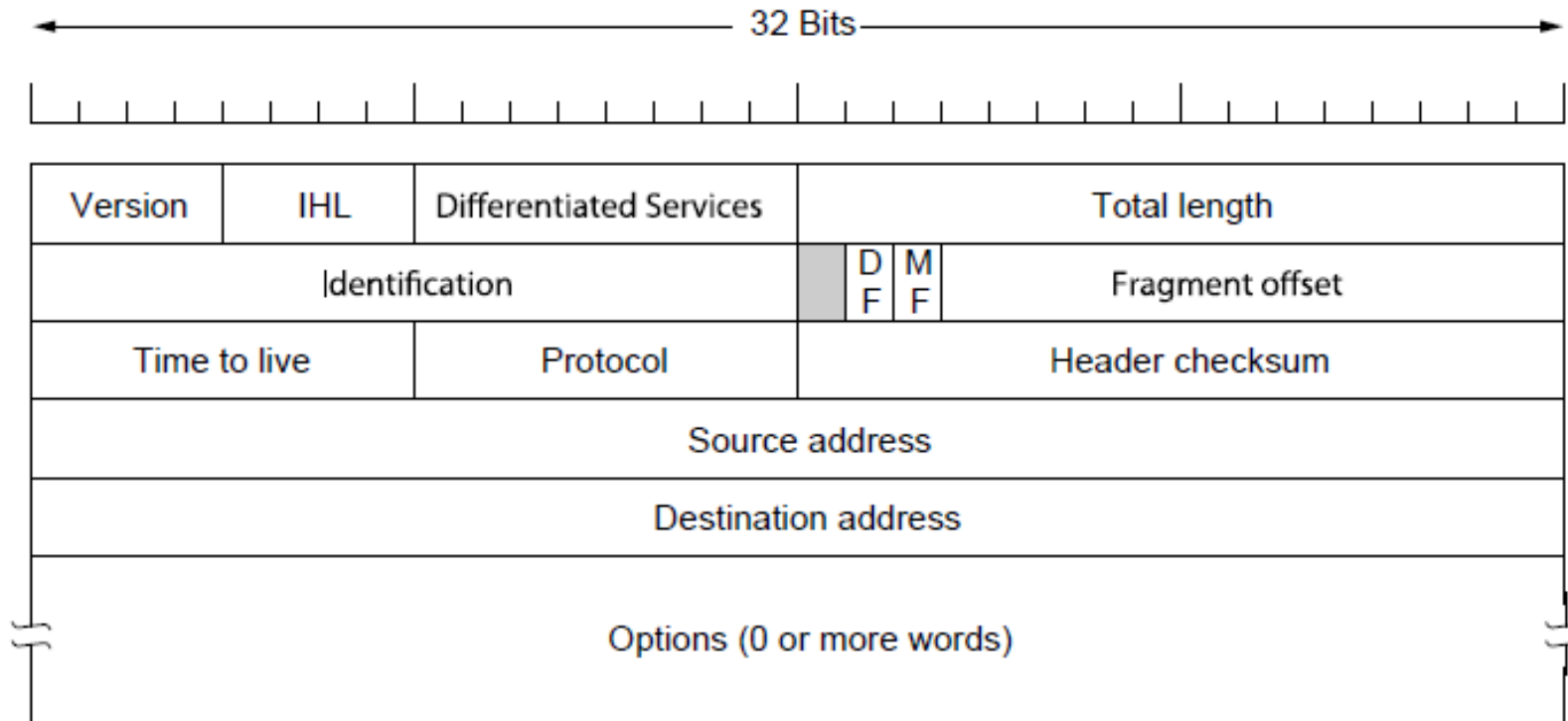- BGP—The Exterior Gateway Routing Protocol »

Network Layer in the Internet (3)

- Internet is an interconnected collection of many networks that is held together by the IP protocol
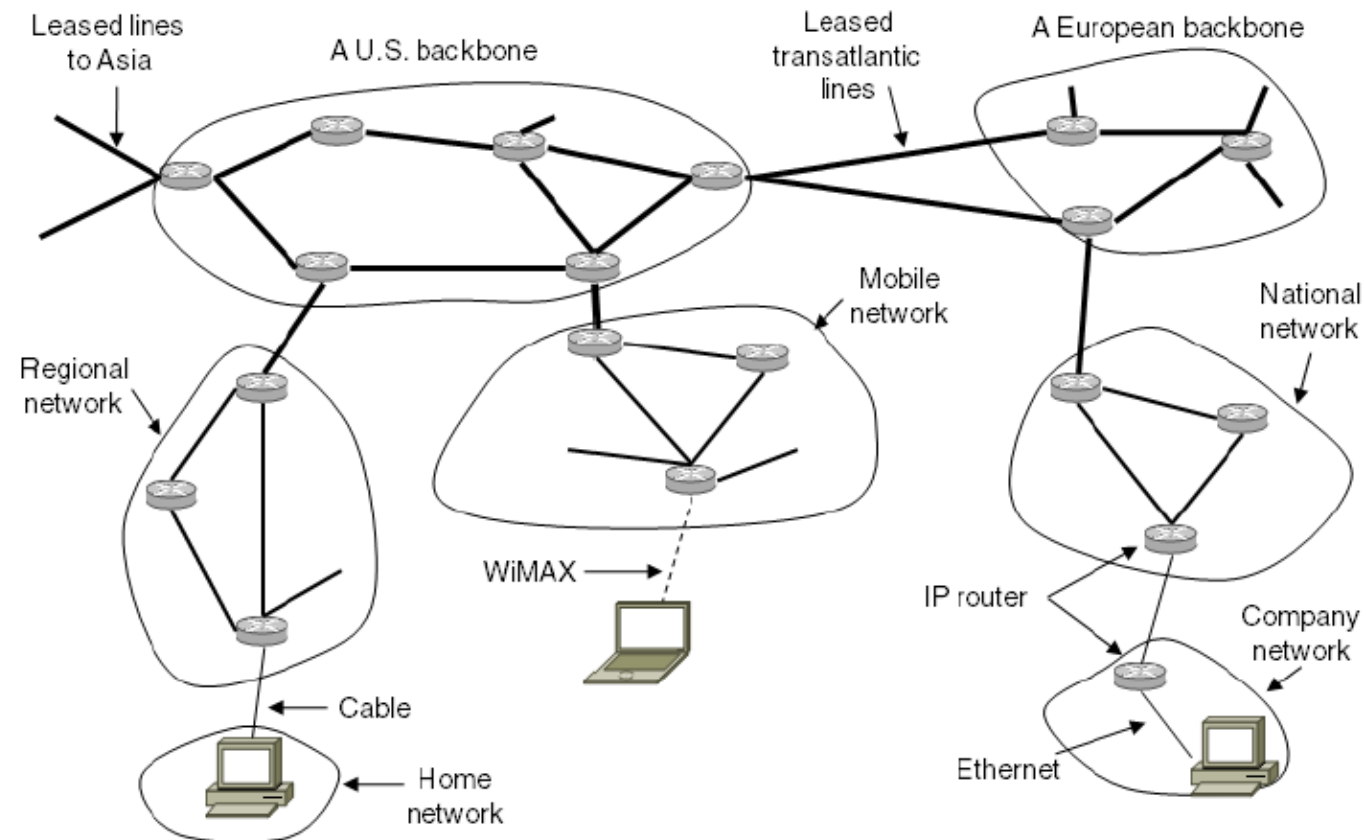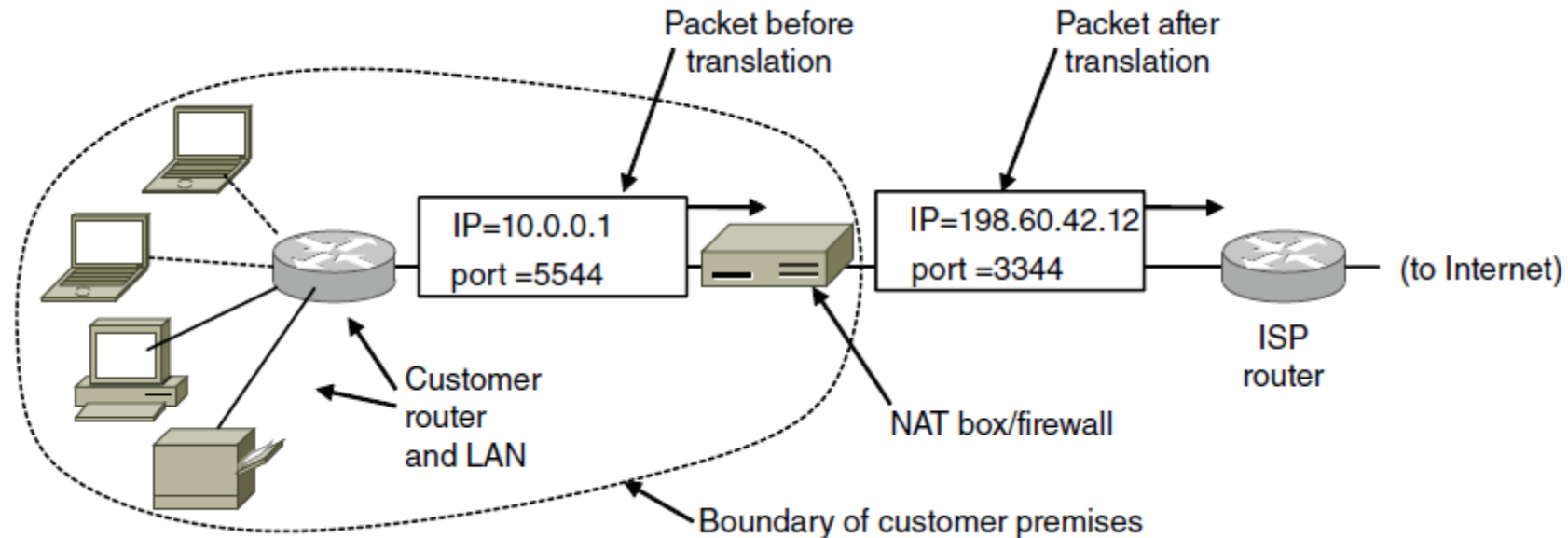
IP Version 4 Protocol (1)

IPv4 (Internet Protocol) header is carried on all packets and has fields for the key parts of the protocol:
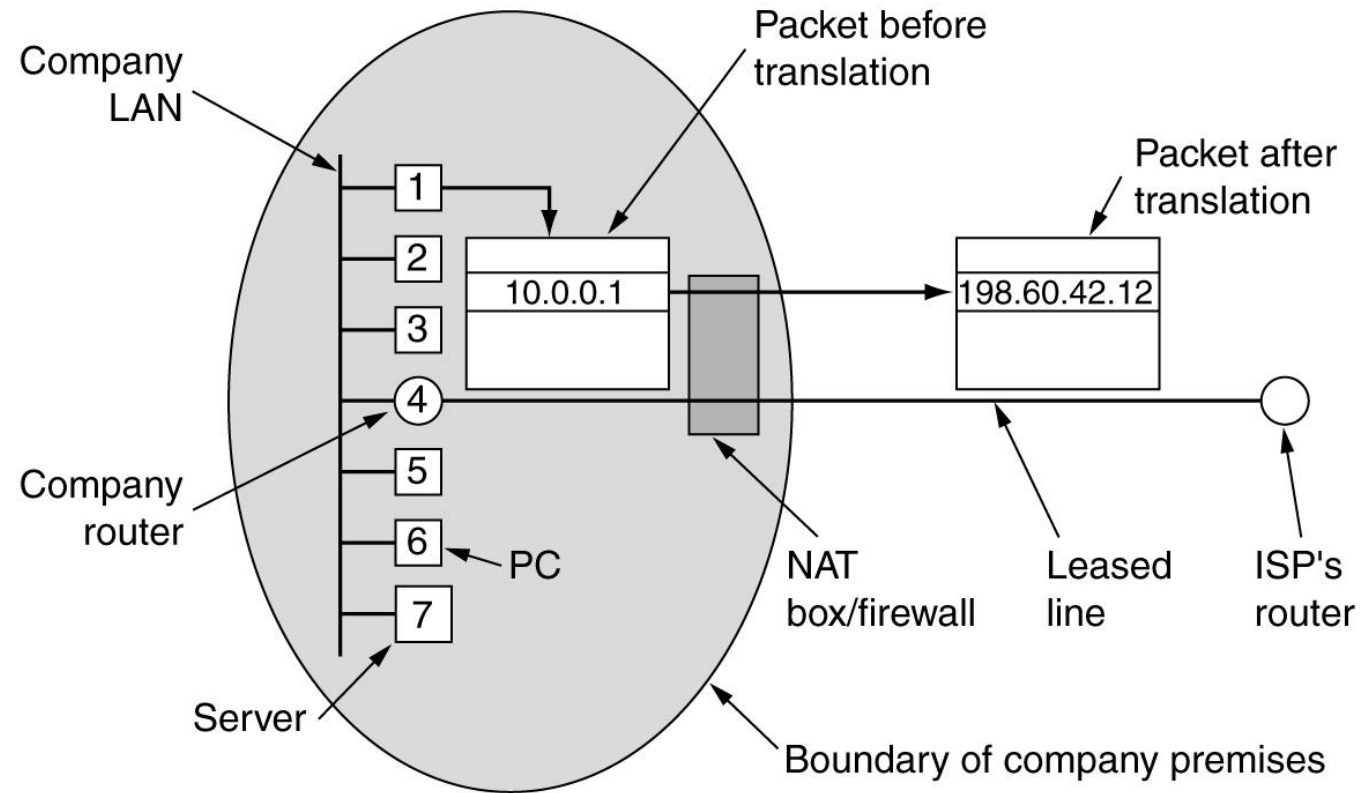
IP Addresses (6) – NAT

NAT (Network Address Translation) box maps one external IP address to many internal IP addresses

- Uses TCP/UDP port to tell connections apart
- Violates layering; very common in homes, etc.

Packet before translation

Packet after translation

IP=10.0.0.1
port =5544

IP=198.60.42.12
port =3344

(to Internet)

ISP router

Customer router and LAN

NAT box/firewall

Boundary of customer premises

NAT – Network Address Translation

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Internet Control Protocols (1)

IP works with the help of several control protocols:

- ICMP is a companion to IP that returns error info
  - Required, and used in many ways, e.g., for traceroute
- ARP finds Ethernet address of a local IP address
  - Glue that is needed to send any IP packets
  - Host queries an address and the owner replies
- DHCP assigns a local IP address to a host
  - Gets host started by automatically configuring it
 - Host sends request to server, which grants a lease

Internet Control Protocols (2)

Main ICMP (Internet Control Message Protocol) types:

| Message type	Description
Destination unreachable	Packet could not be delivered
Time exceeded	Time to live field hit 0
Parameter problem	Invalid header field
Source quench	Choke packet
Redirect	Teach a router about geography
Echo and Echo reply	Check if a machine is alive
Timestamp request/reply	Same as Echo, but with timestamp
Router advertisement/solicitation	Find a nearby router

Internet Control Protocols (3)

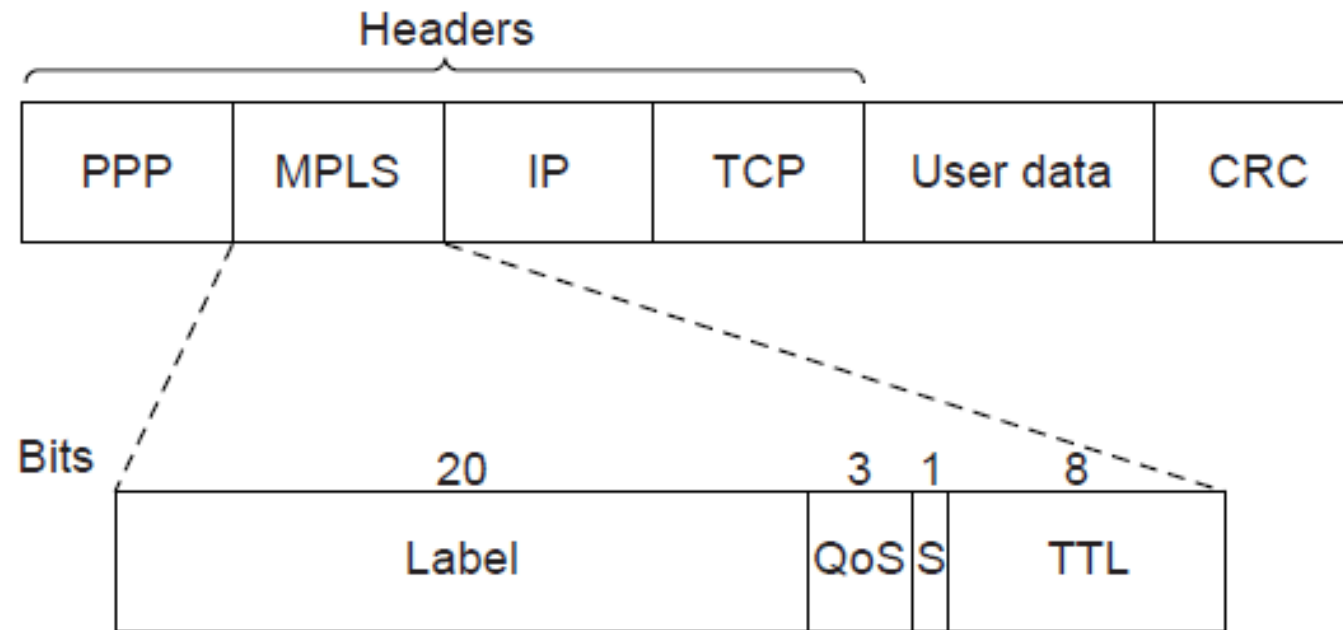- ARP (Address Resolution Protocol) lets nodes find target Ethernet addresses [pink] from their IP addresses
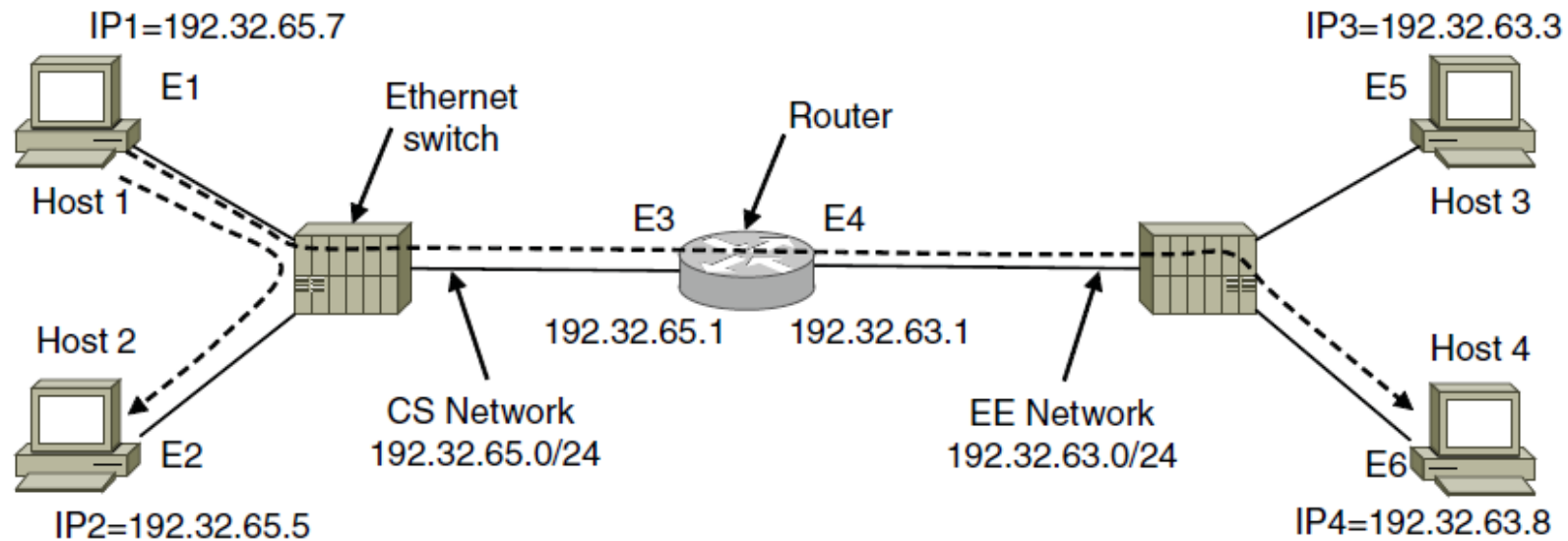
Frame	Source IP	Source Eth.	Destination IP	Destination Eth.
Host 1 to 2, on CS net	IP1	E1	IP2	E2
Host 1 to 4, on CS net	IP1	E1	IP4	E3
Host 1 to 4, on EE net	IP1	E4	IP4	E6

Dynamic Host Configuration Protocol
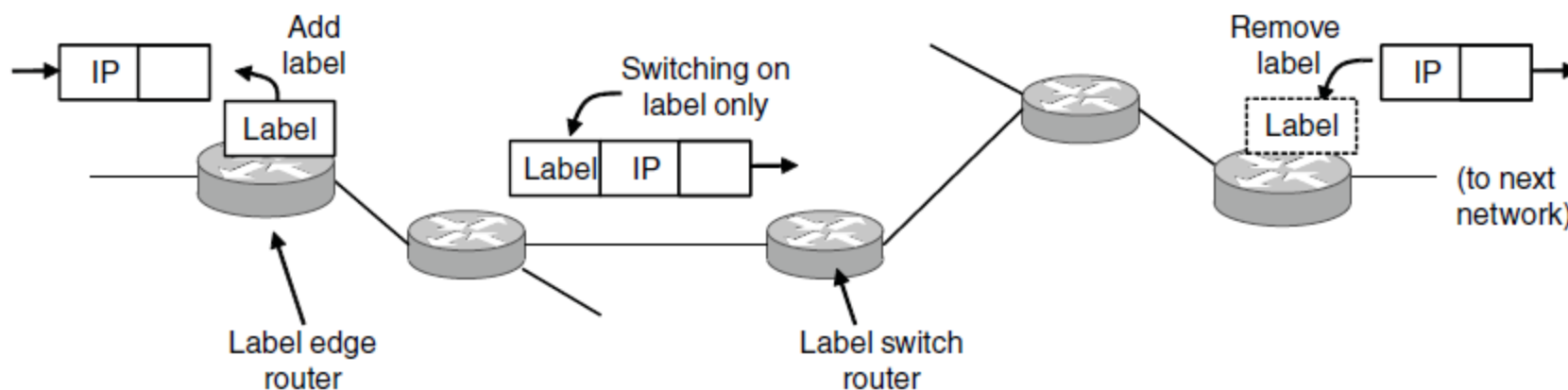
Operation of DHCP.
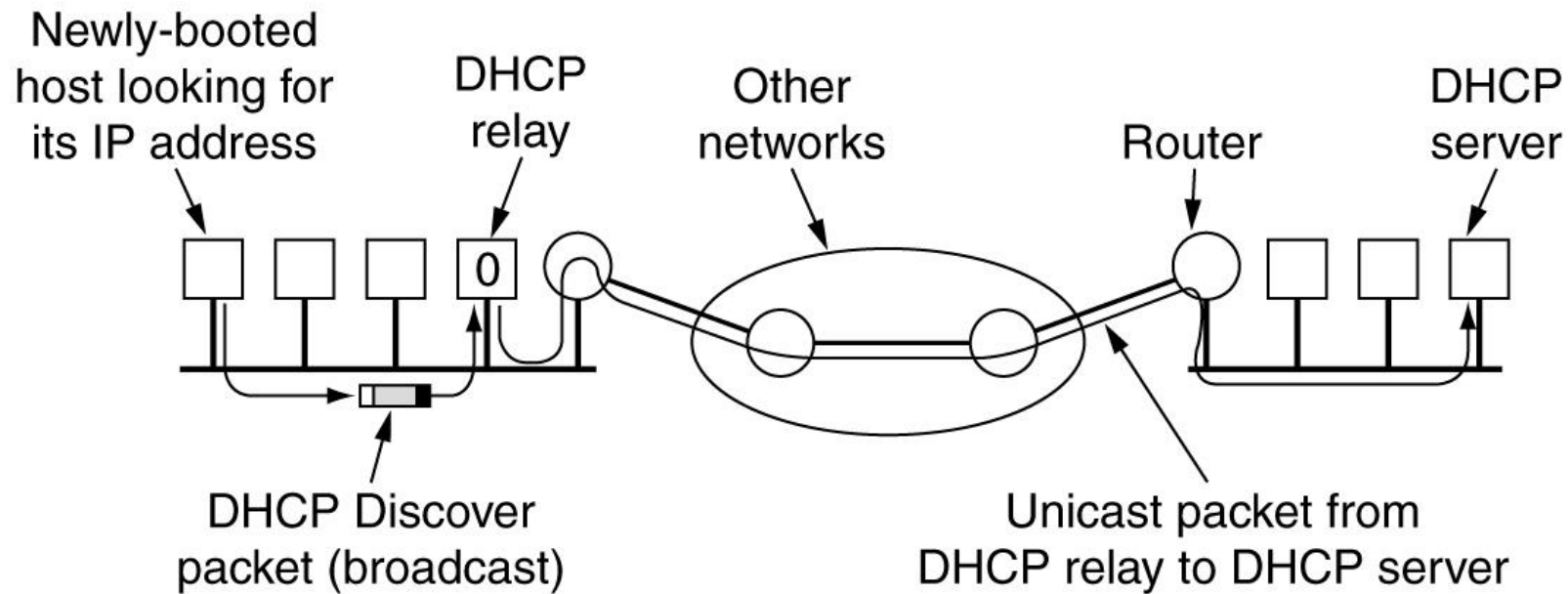
Label Switching and MPLS (1)

Transmitting a TCP segment using IP, MPLS, and PPP.

Label Switching and MPLS (2)

Forwarding an IP packet through an MPLS network