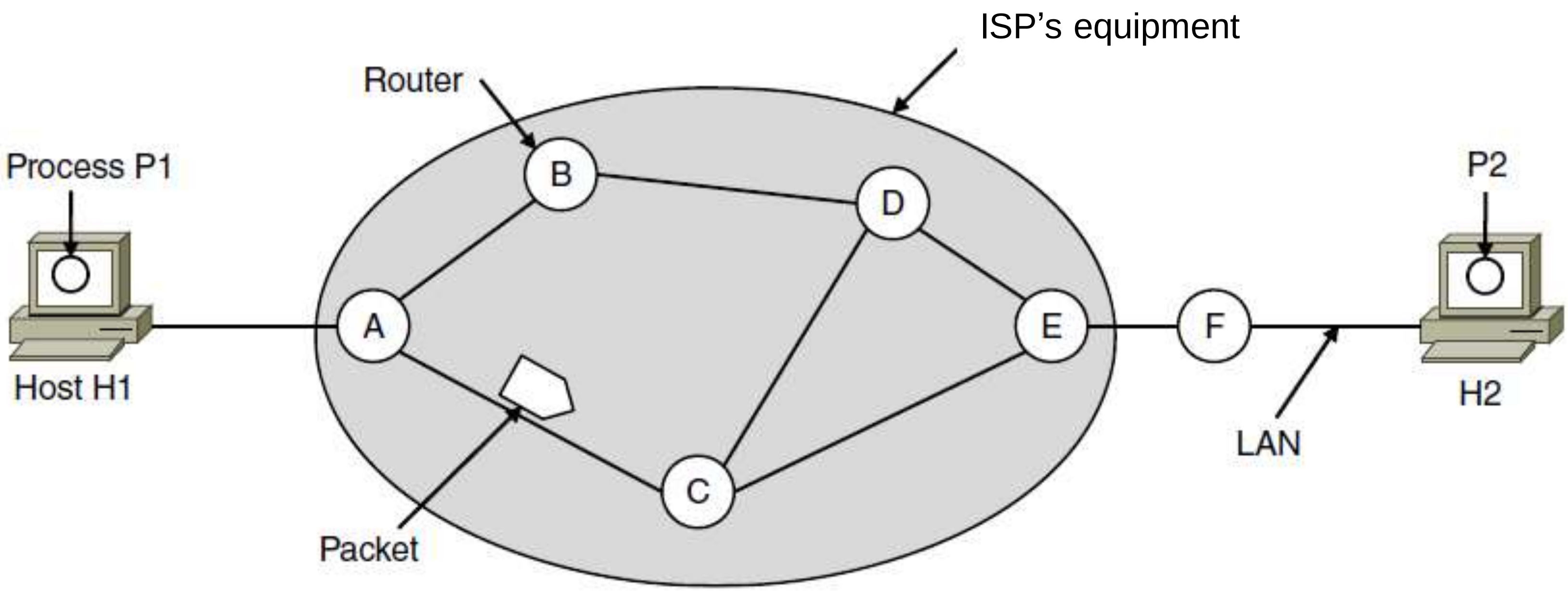
The Network Layer

Chapter 5

Network Layer Design Issues

- Store-and-forward packet switching
- Services provided to transport layer
- Implementation of connectionless service
- Implementation of connection-oriented service
- Comparison of virtual-circuit and datagram networks

Store-and-Forward Packet Switching

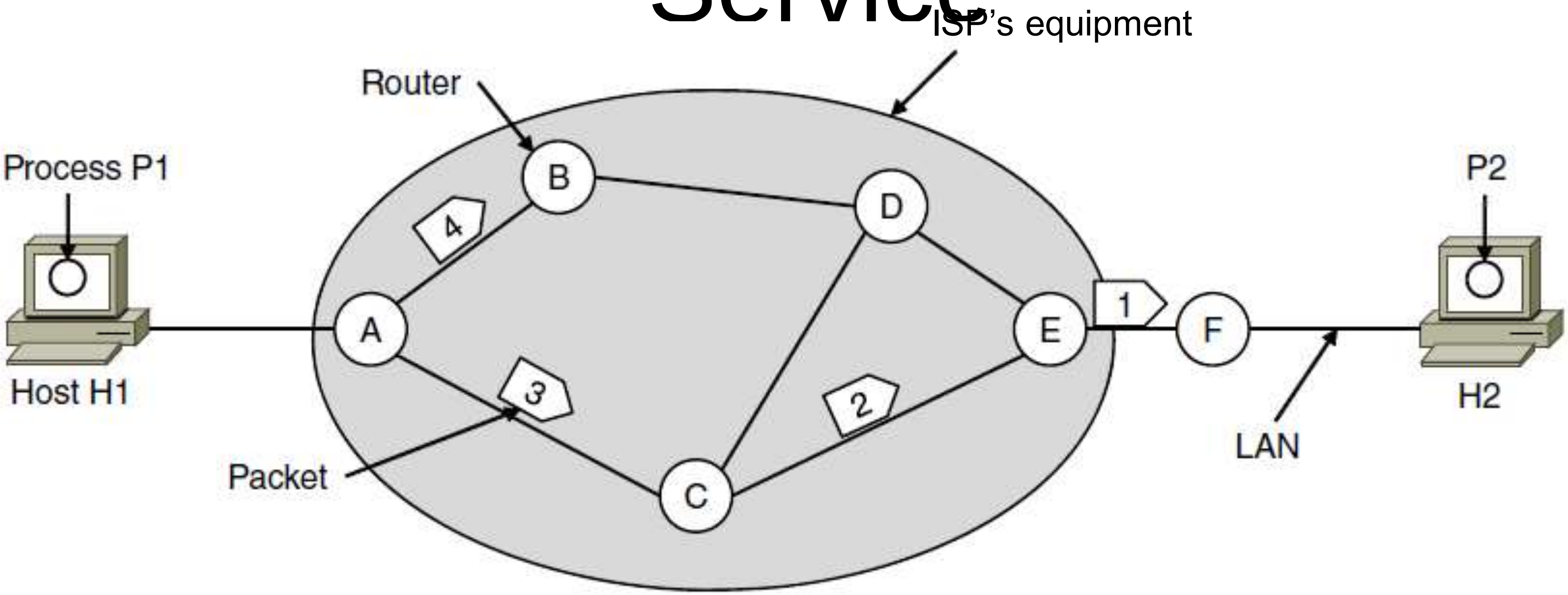


The environment of the network layer protocols.

Services Provided to the Transport Layer

1. Services independent of router technology.
2. Transport layer shielded from number, type, topology of routers.
3. Network addresses available to transport layer use uniform numbering plan
   - even across LANs and WANs

Implementation of Connectionless Service



A's table (initially)

A	
B	B
C	C
D	B
E	C
F	C

Dest. Line

A's table (later)

A	
B	B
C	C
D	B
E	D
F	D

C's Table

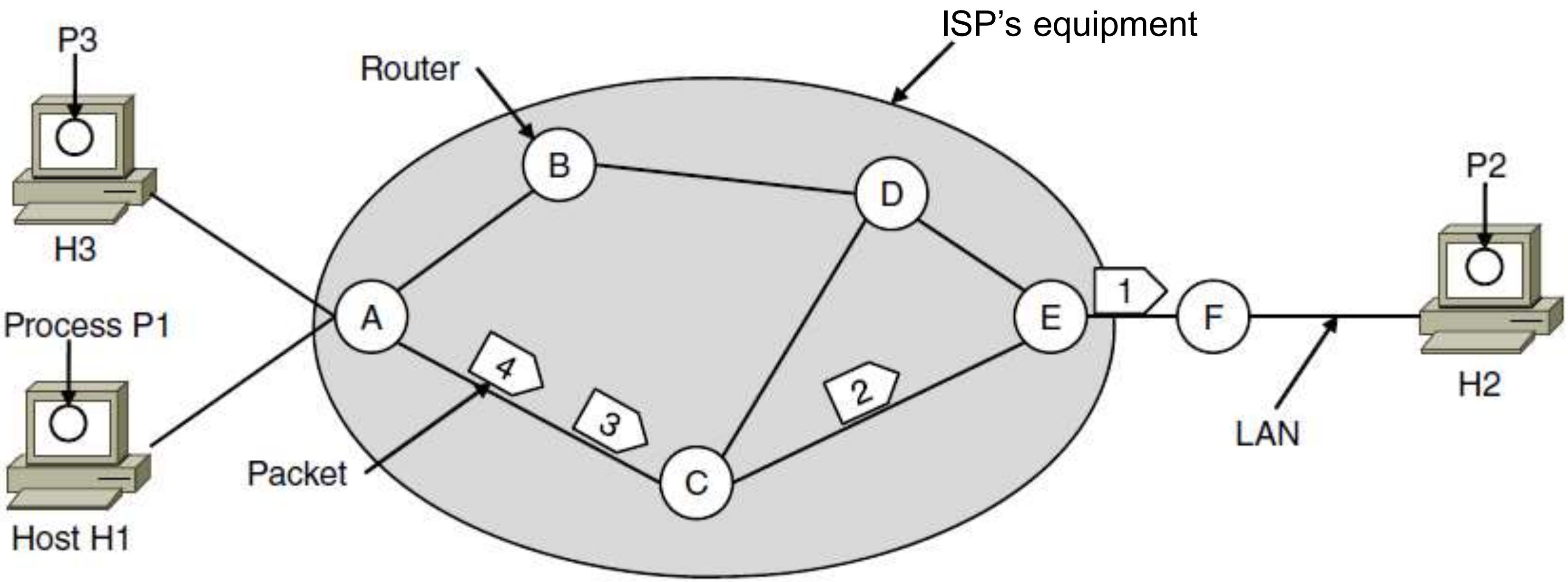
A	A
B	A
C	
D	E
E	E
F	E

E's Table

A	C
B	D
C	C
D	D
E	
F	F

Routing within a datagram network

Implementation of Connection-Oriented Service



A's table

In		Out	
H1	1	C	1
H3	1	C	2

C's Table

A	1	E	1
A	2	E	2

E's Table

C	1	F	1
C	2	F	2

Routing within a virtual-circuit network

Comparison of Virtual-Circuit and Datagram Networks

Issue	Datagram network	Virtual-circuit network
Circuit setup	Not needed	Required
Addressing	Each packet contains the full source and destination address	Each packet contains a short VC number
State information	Routers do not hold state information about connections	Each VC requires router table space per connection
Routing	Each packet is routed independently	Route chosen when VC is set up; all packets follow it
Effect of router failures	None, except for packets lost during the crash	All VCs that passed through the failed router are terminated
Quality of service	Difficult	Easy if enough resources can be allocated in advance for each VC
Congestion control	Difficult	Easy if enough resources can be allocated in advance for each VC

Comparison of datagram and virtual-circuit networks

Routing Algorithms

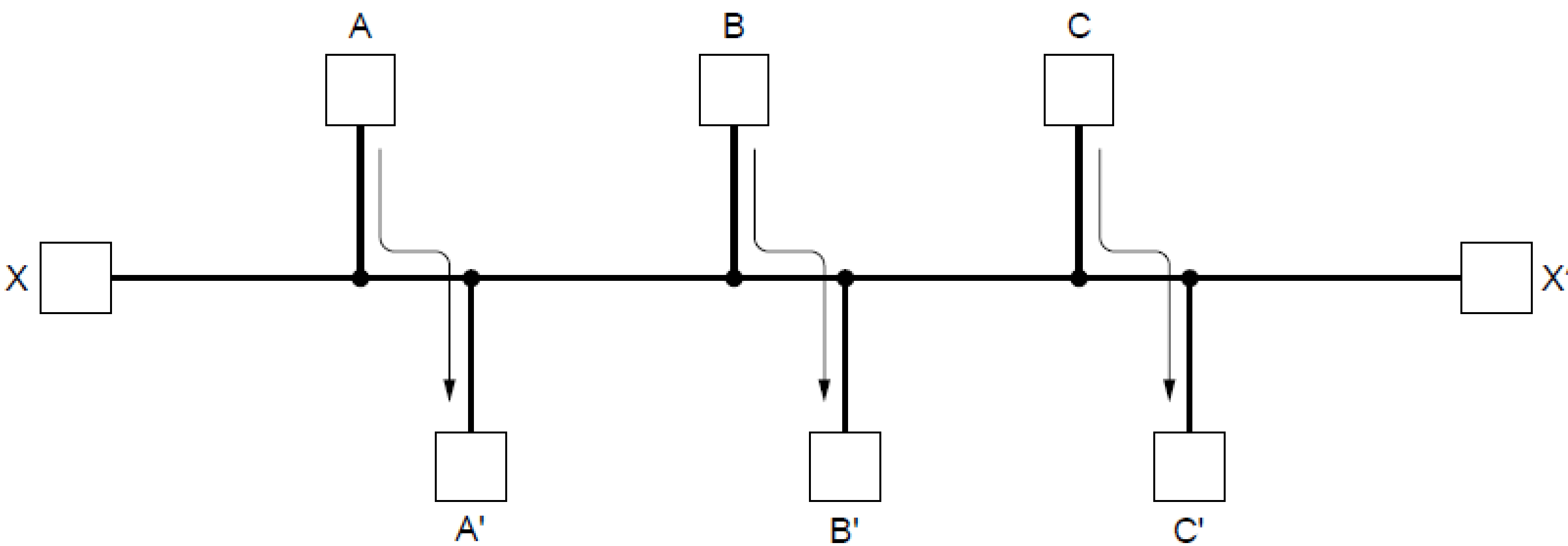
- Optimality principle
- Shortest path algorithm
- Flooding
- Distance vector routing

Routing Algorithms

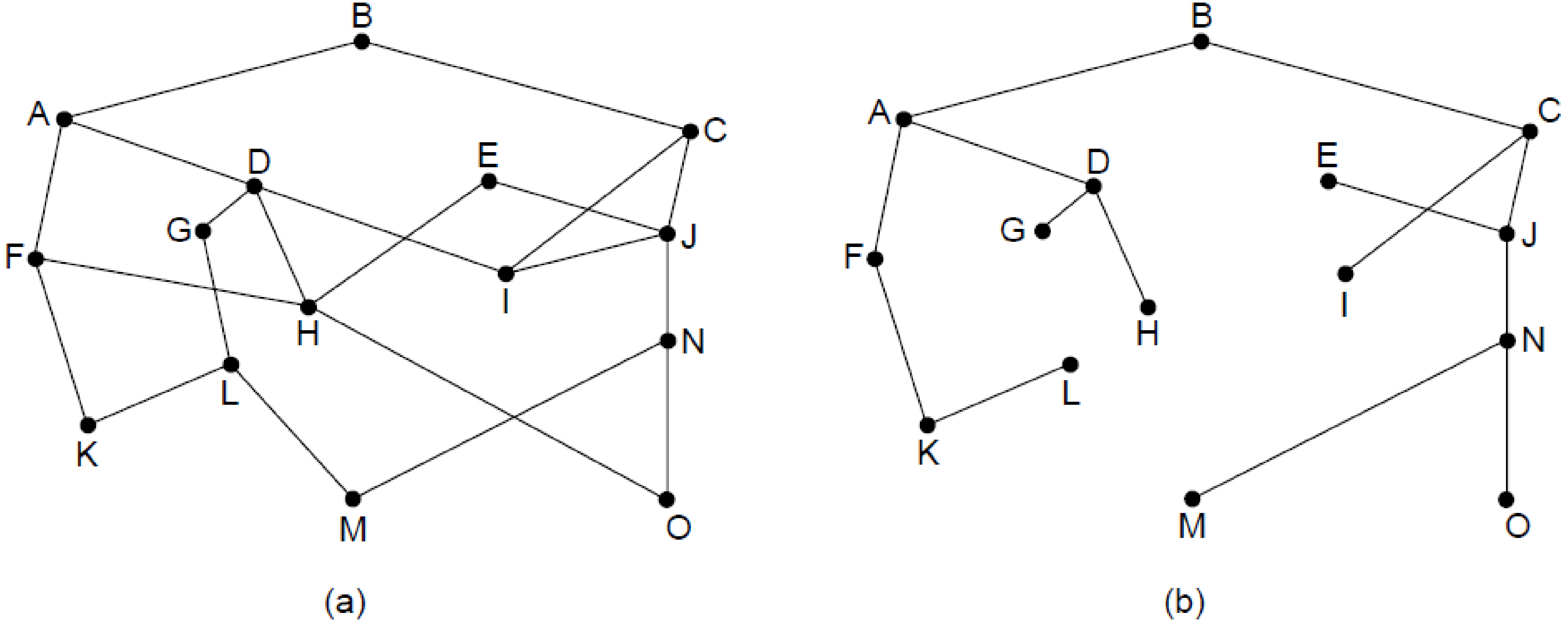
- Broadcast routing
- Multicast routing
- Anycast routing
- Routing for mobile hosts
- Routing in ad hoc networks

Fairness vs. Efficiency

Network with a conflict between fairness and efficiency.

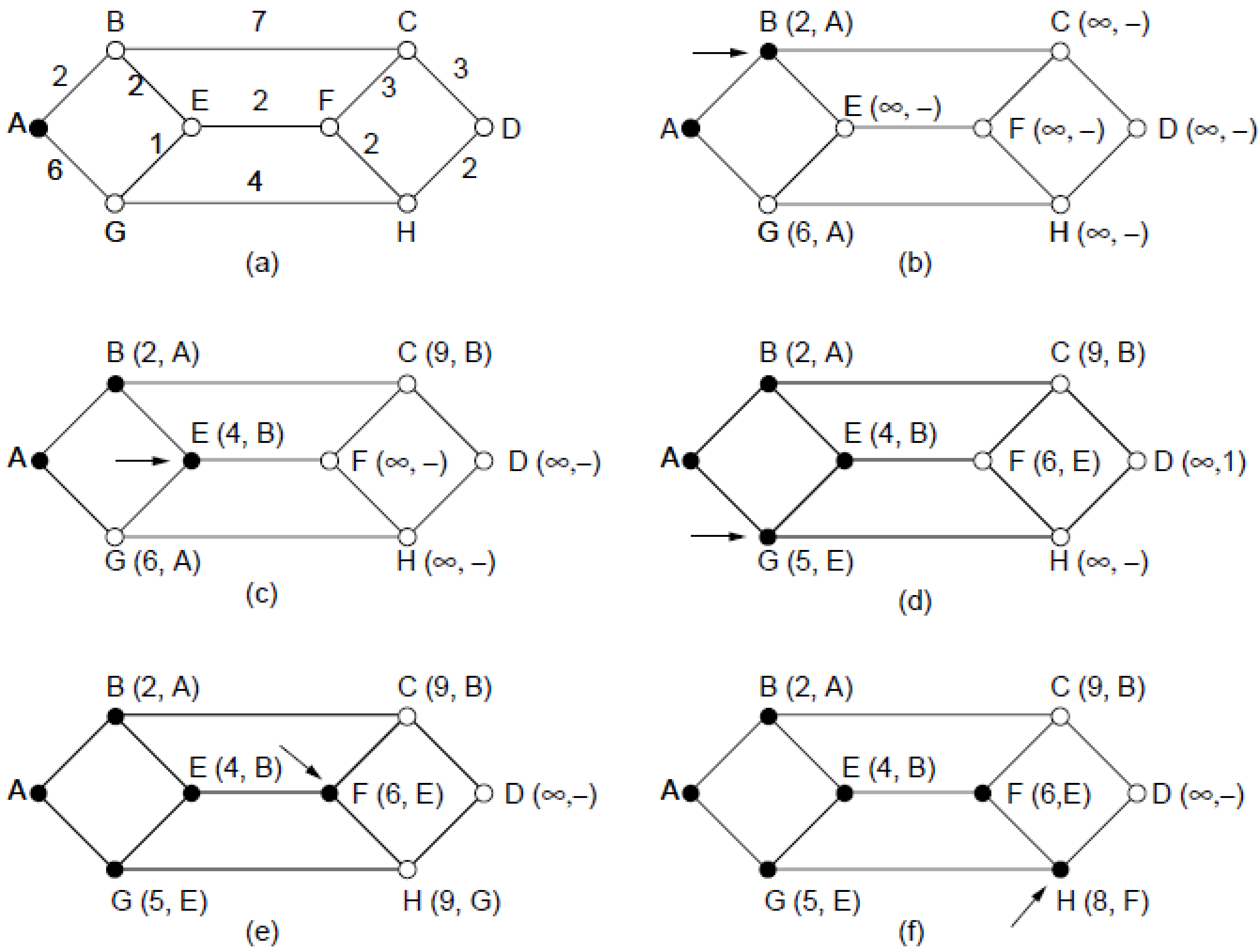


The Optimality Principle



(a) A network. (b) A sink tree for router *B.*

Shortest Path Algorithm



The first five steps used in computing the shortest path from *A to D.* The arrows indicate the working node

Shortest Path Algorithm (2)

```
#define MAX_NODES 1024                      /* maximum number of nodes */
#define INFINITY 1000000000                 /* a number larger than every maximum path */
int n, dist[MAX_NODES][MAX_NODES];          /* dist[i][j] is the distance from i to j */

void shortest_path(int s, int t, int path[])
{ struct state {                            /* the path being worked on */
      int predecessor;                      /* previous node */
      int length;                           /* length from source to this node */
      enum {permanent, tentative} label;    /* label state */
  } state[MAX_NODES];

  int i, k, min;
  struct state *p;

   . . .
```

Dijkstra’s algorithm to compute the shortest path through a graph.

Shortest Path Algorithm (3)

. . .

```
for (p = &state[0]; p < &state[n]; p++) {        /* initialize state */
     p->predecessor = –1;
     p->length = INFINITY;
     p->label = tentative;
}
state[t].length = 0;  state[t].label = permanent;
k = t;                                           /* k is the initial working node */
do {                                             /* Is there a better path from k? */
     for (i = 0; i < n; i++)                     /* this graph has n nodes */
          if (dist[k][i] != 0 && state[i].label == tentative) {
                if (state[k].length + dist[k][i] < state[i].length) {
                      state[i].predecessor = k;
                      state[i].length = state[k].length + dist[k][i];
                }
          }
```

. . .

Dijkstra’s algorithm to compute the shortest path through a graph.

Shortest Path Algorithm (4)

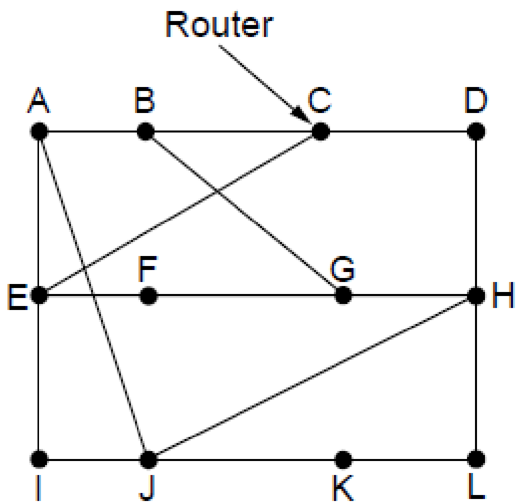
. . .

```
        /* Find the tentatively labeled node with the smallest label. */
        k = 0; min = INFINITY;
        for (i = 0; i < n; i++)
                if (state[i].label == tentative && state[i].length < min) {
                        min = state[i].length;
                        k = i;
                }
        state[k].label = permanent;
    } while (k != s);

    /* Copy the path into the output array. */
    i = 0;  k = s;
    do {path[i++] = k; k = state[k].predecessor; } while (k >= 0);
}
```

Dijkstra’s algorithm to compute the shortest path through a graph.

Distance Vector Routing



(a)

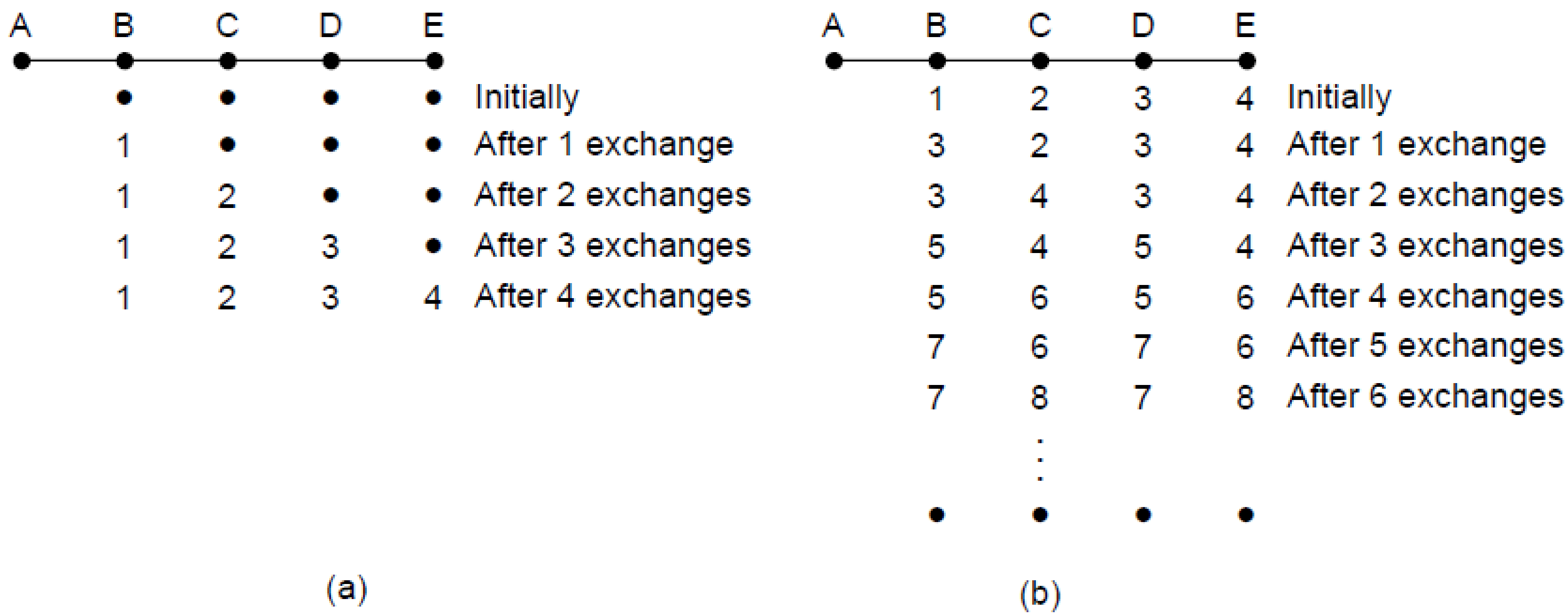
To	A	I	H	K	New estimated delay from J	Line
A	0	24	20	21	8	A
B	12	36	31	28	20	A
C	25	18	19	36	28	I
D	40	27	8	24	20	H
E	14	7	30	22	17	I
F	23	20	19	40	30	I
G	18	31	6	31	18	H
H	17	20	0	19	12	H
I	21	0	14	22	10	I
J	9	11	7	10	0	–
K	24	22	22	0	6	K
L	29	33	9	9	15	K
	JA delay is 8	JI delay is 10	JH delay is 12	JK delay is 6	New routing table for J	

Vectors received from J's four neighbors

(b)

(a) A network.
(b) Input from *A, I, H, K, and the new routing table* for *J.*

The Count-to-Infinity Problem



The count-to-infinity problem

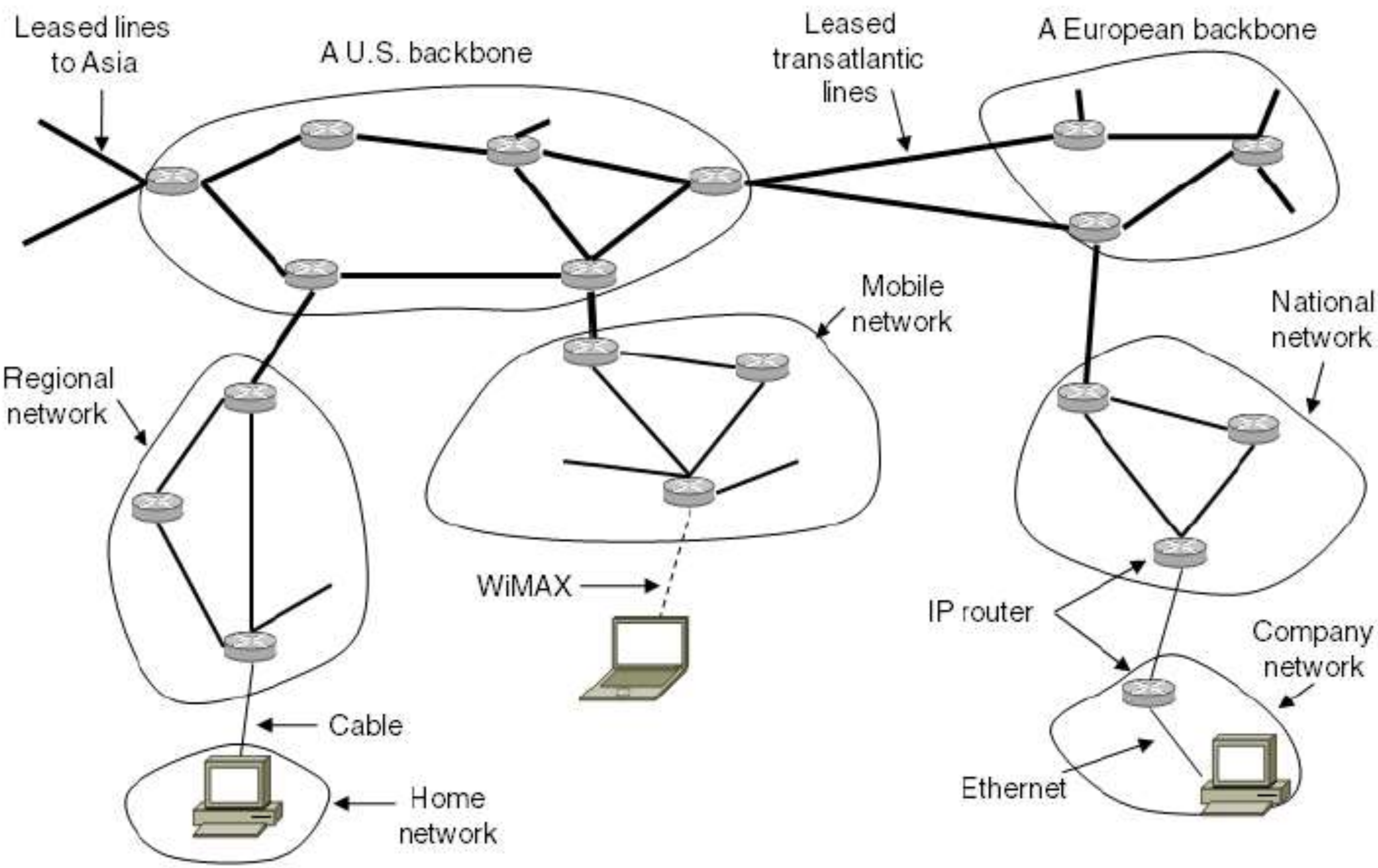
How Networks Differ

Item	Some Possibilities
Service offered	Connectionless versus connection oriented
Addressing	Different sizes, flat or hierarchical
Broadcasting	Present or absent (also multicast)
Packet size	Every network has its own maximum
Ordering	Ordered and unordered delivery
Quality of service	Present or absent; many different kinds
Reliability	Different levels of loss
Security	Privacy rules, encryption, etc.
Parameters	Different timeouts, flow specifications, etc.
Accounting	By connect time, packet, byte, or not at all

The Network Layer in the Internet

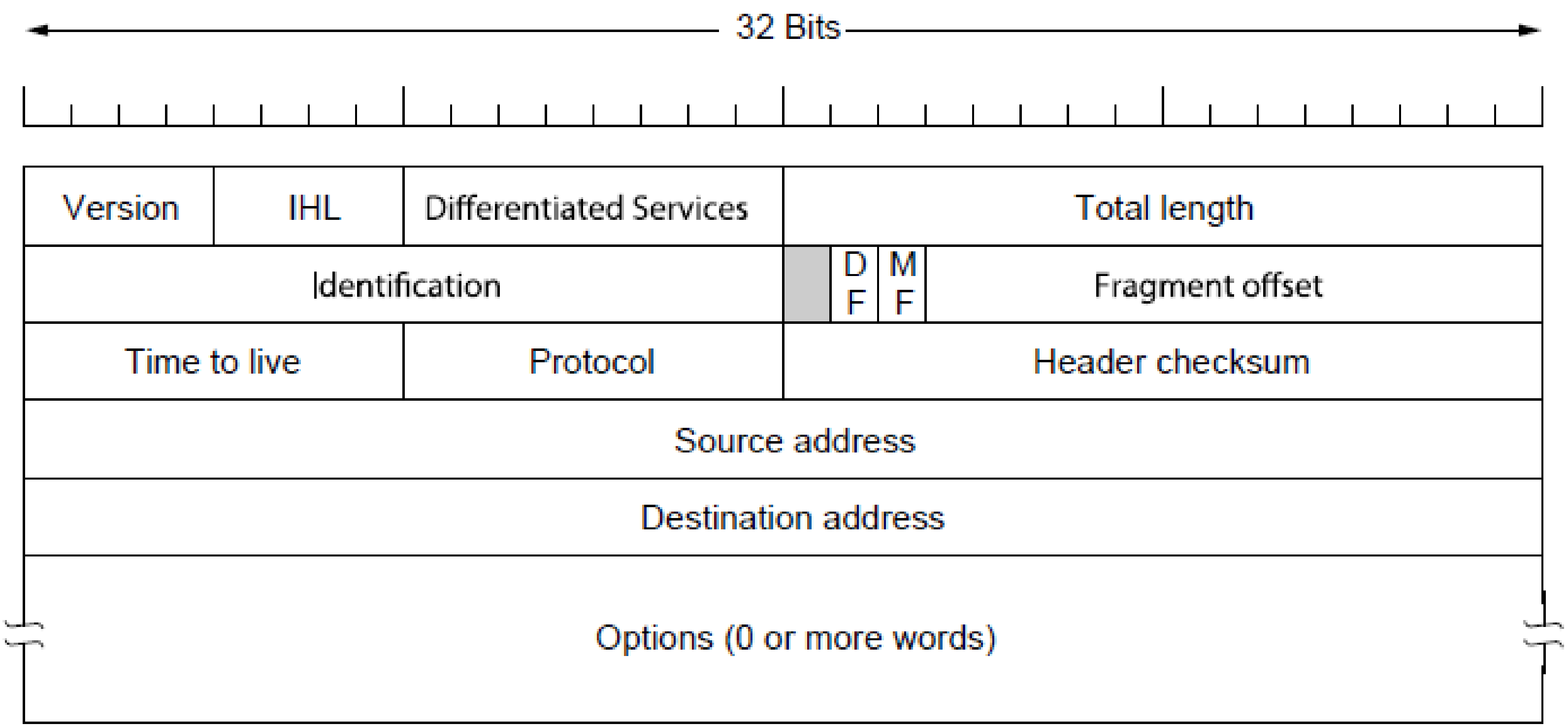
- The IP Version 4 Protocol
- IP Addresses
- IP Version 6
- Internet Control Protocols
- Label Switching and MPLS
- OSPF—An Interior Gateway Routing Protocol
- BGP—The Exterior Gateway Routing Protocol
- Internet Multicasting
- Mobile IP

The Network Layer in the Internet



The Internet is an interconnected collection of many networks.

The IP Version 4 Protocol



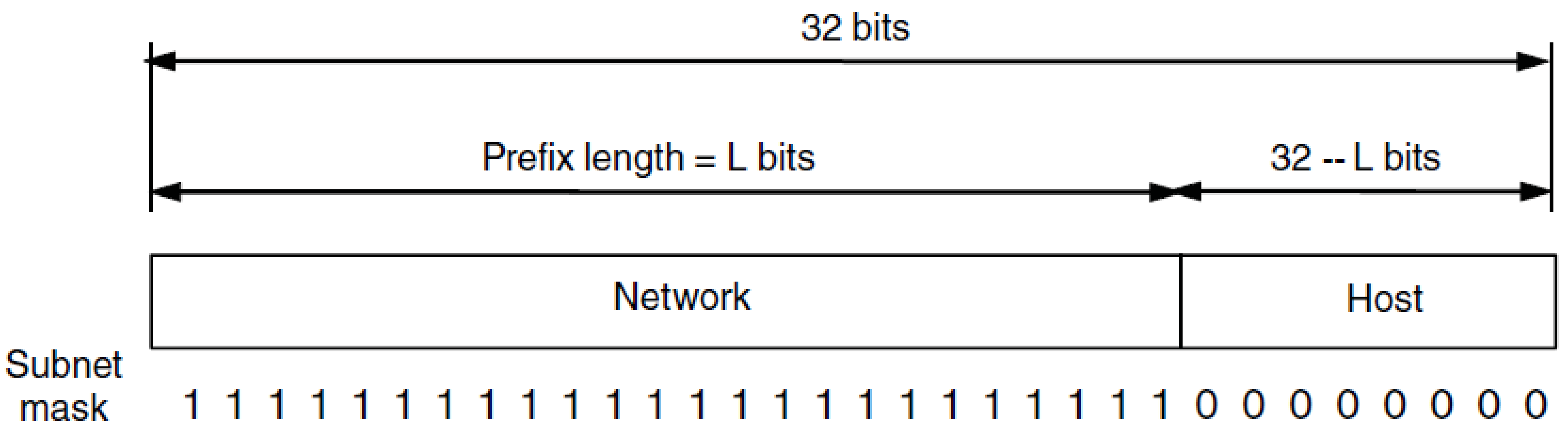
The IPv4 (Internet Protocol) header.

The IP Version 4 Protocol

Option	Description
Security	Specifies how secret the datagram is
Strict source routing	Gives the complete path to be followed
Loose source routing	Gives a list of routers not to be missed
Record route	Makes each router append its IP address
Timestamp	Makes each router append its address and timestamp

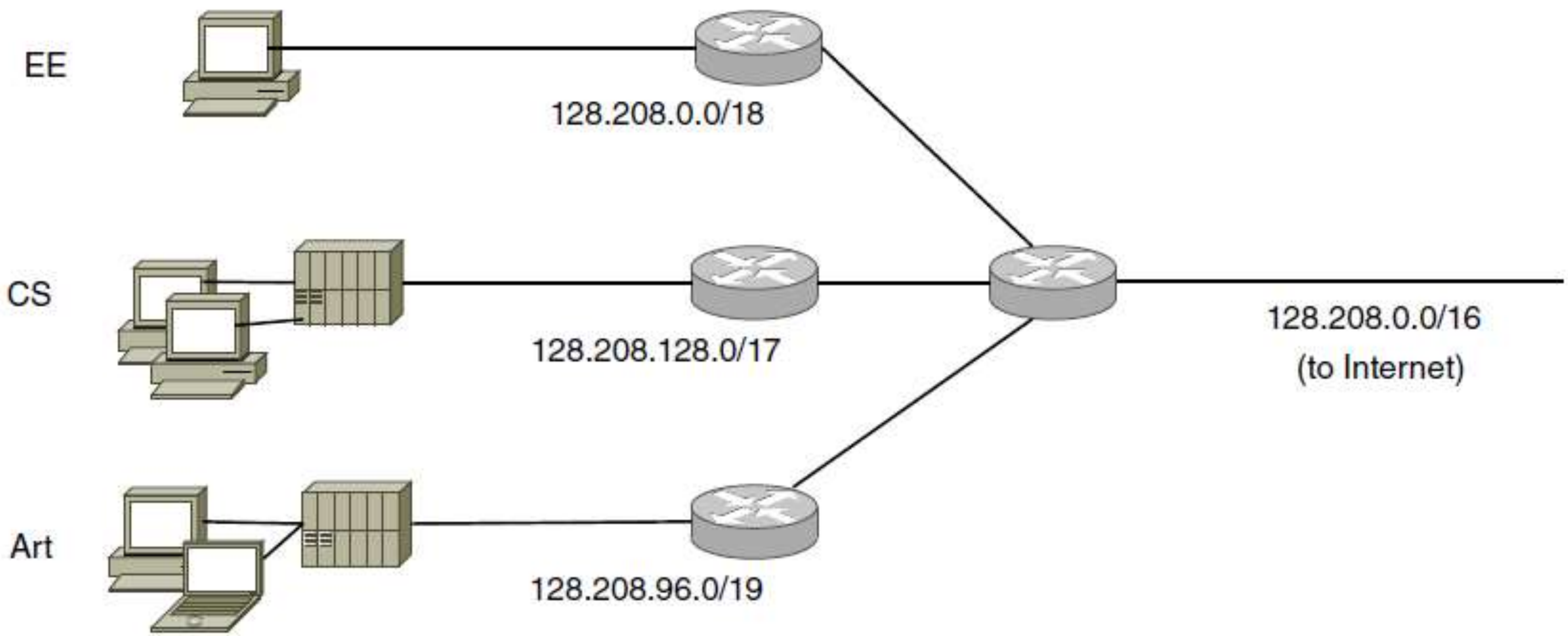
Some of the IP options.

IP Addresses



An IP prefix.

IP Addresses



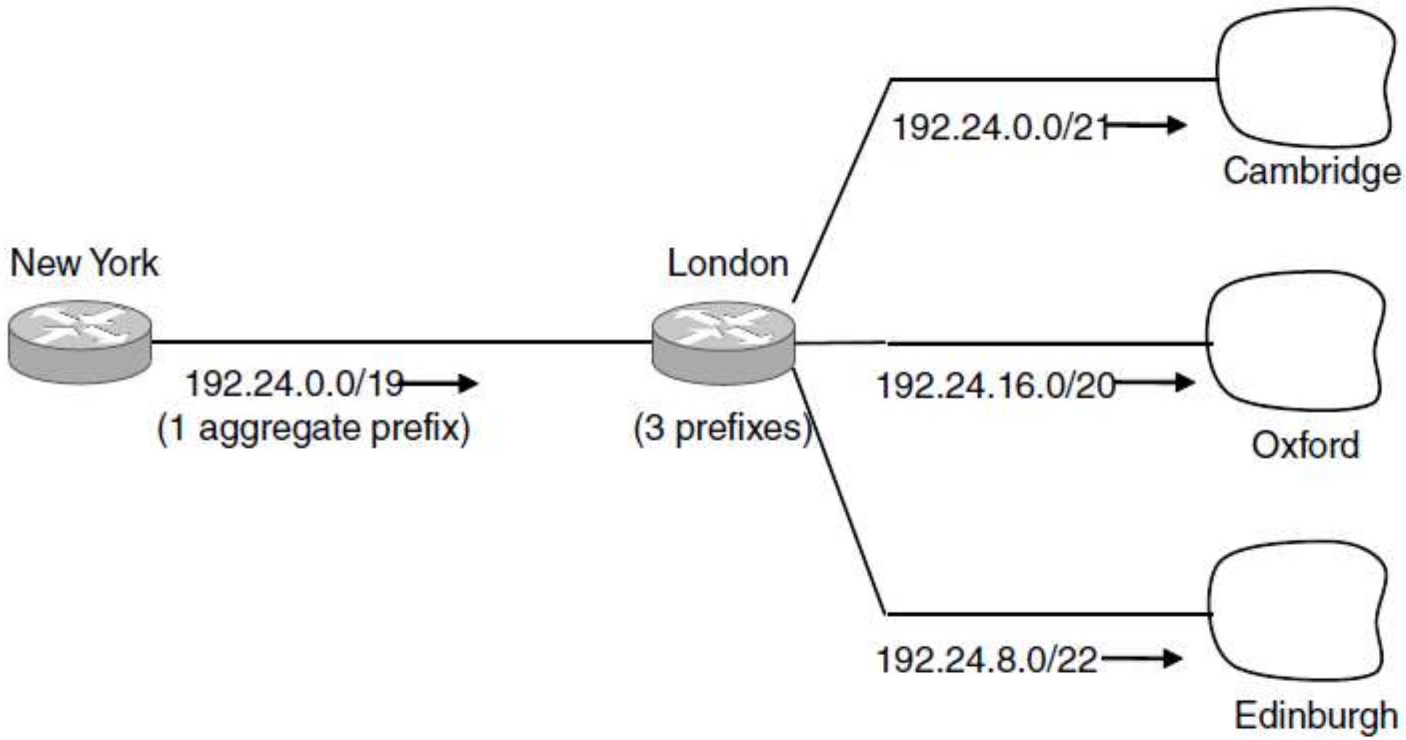
Splitting an IP prefix into separate networks with subnetting.

IP Addresses

University	First address	Last address	How many	Prefix
Cambridge	194.24.0.0	194.24.7.255	2048	194.24.0.0/21
Edinburgh	194.24.8.0	194.24.11.255	1024	194.24.8.0/22
(Available)	194.24.12.0	194.24.15.255	1024	194.24.12/22
Oxford	194.24.16.0	194.24.31.255	4096	194.24.16.0/20

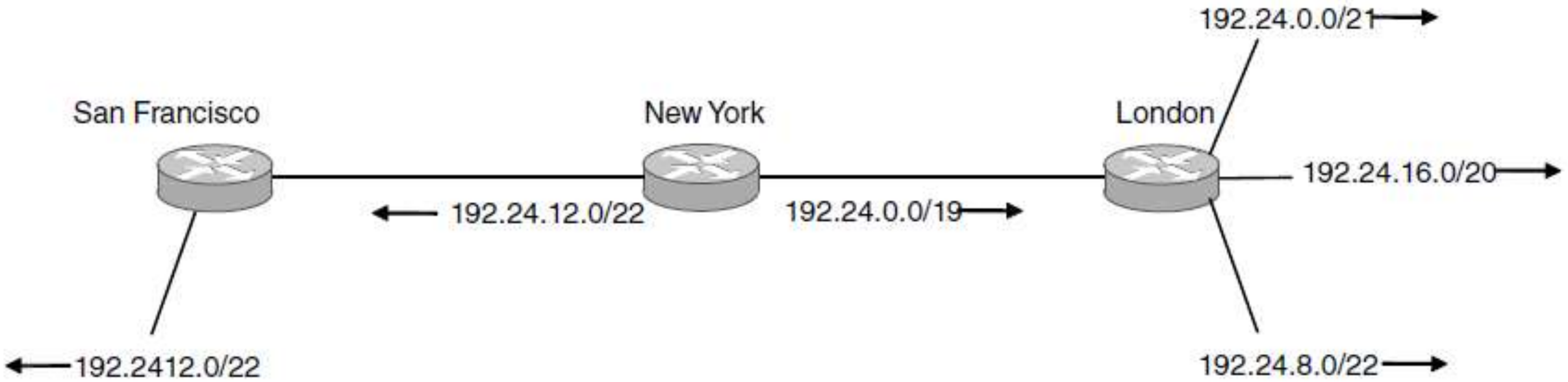
A set of IP address assignments

IP Addresses



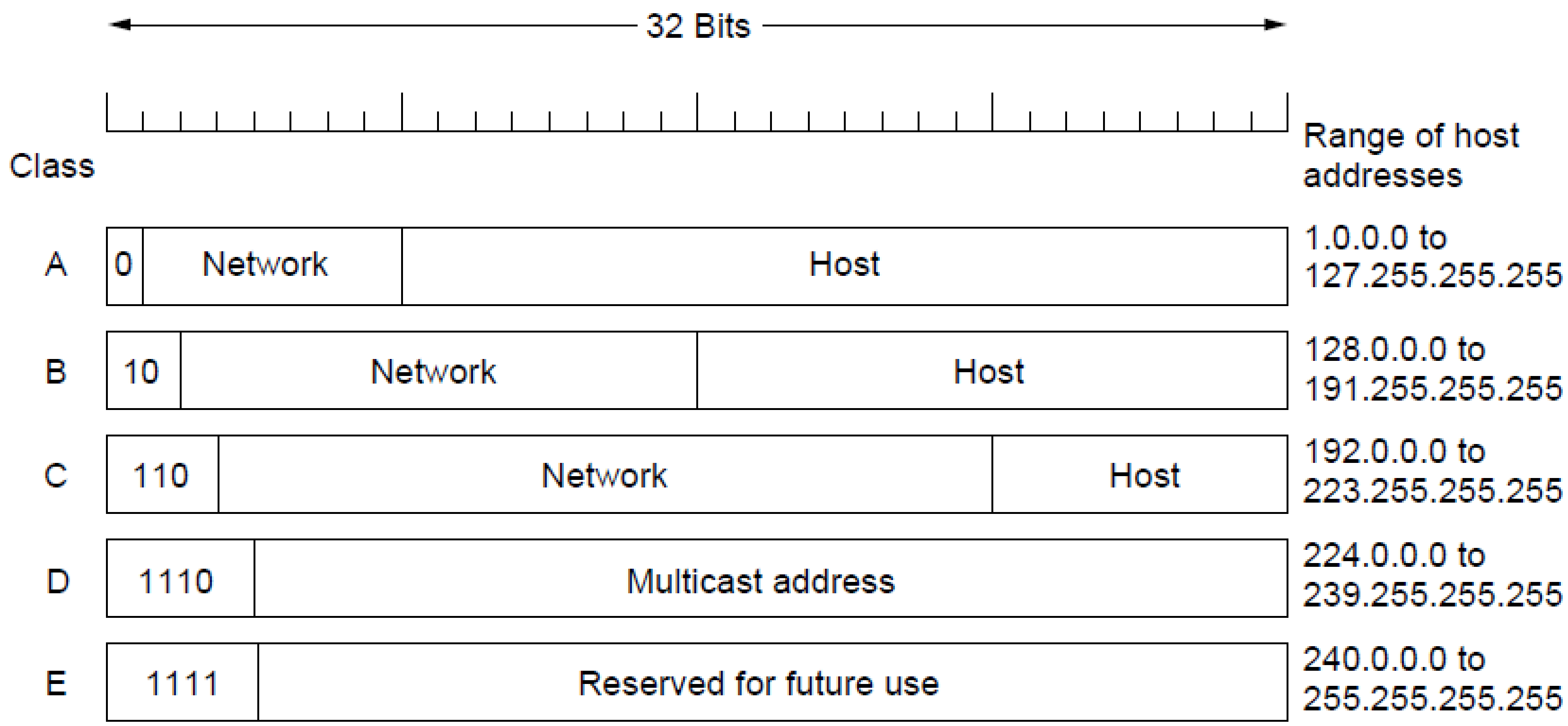
Aggregation of IP prefixes

IP Addresses



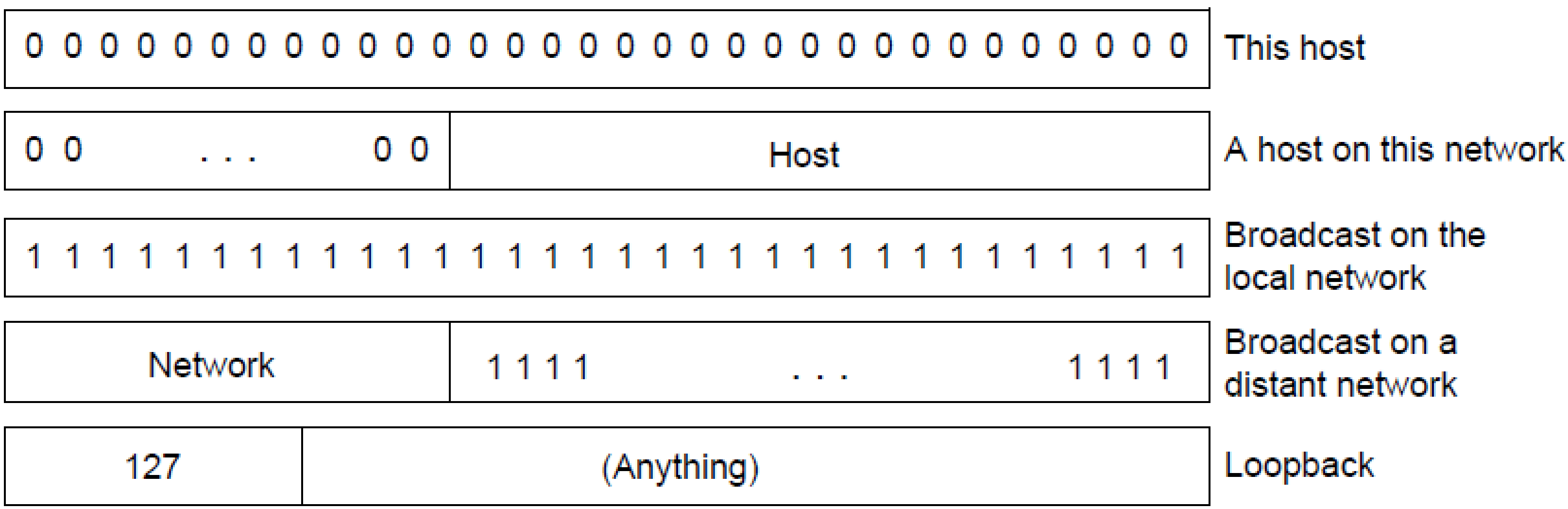
Longest matching prefix routing at the New York router.

IP Addresses



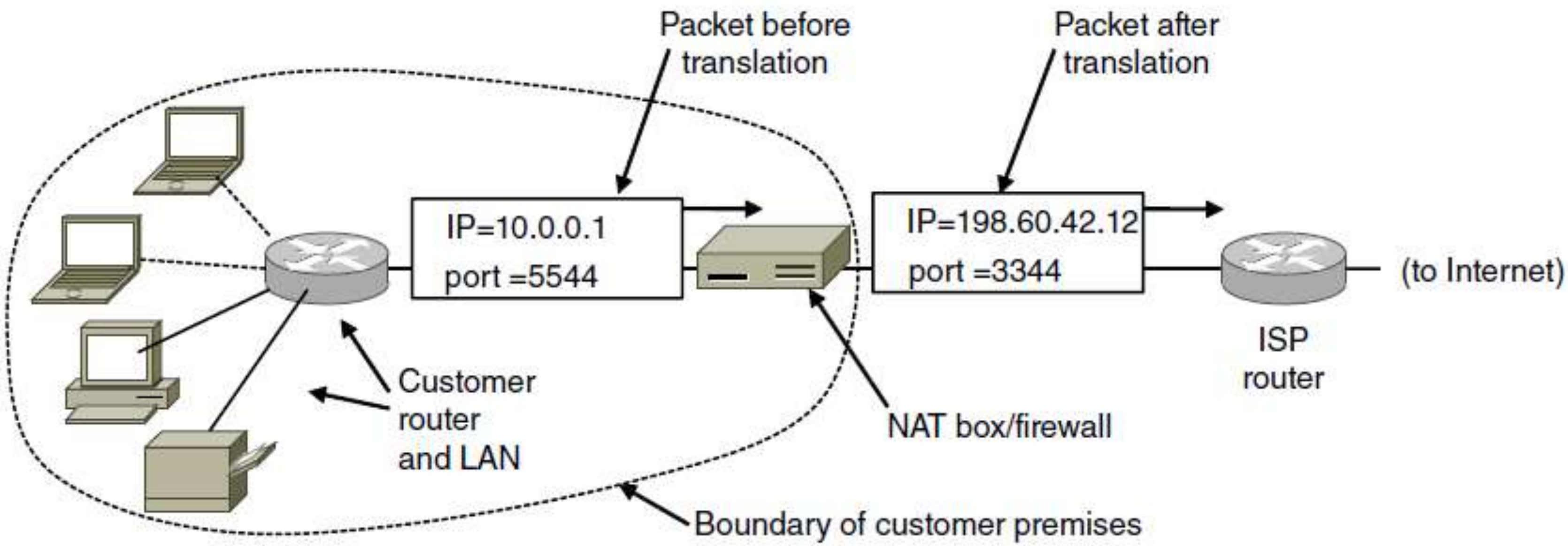
IP address formats

IP Addresses



Special IP addresses

IP Addresses

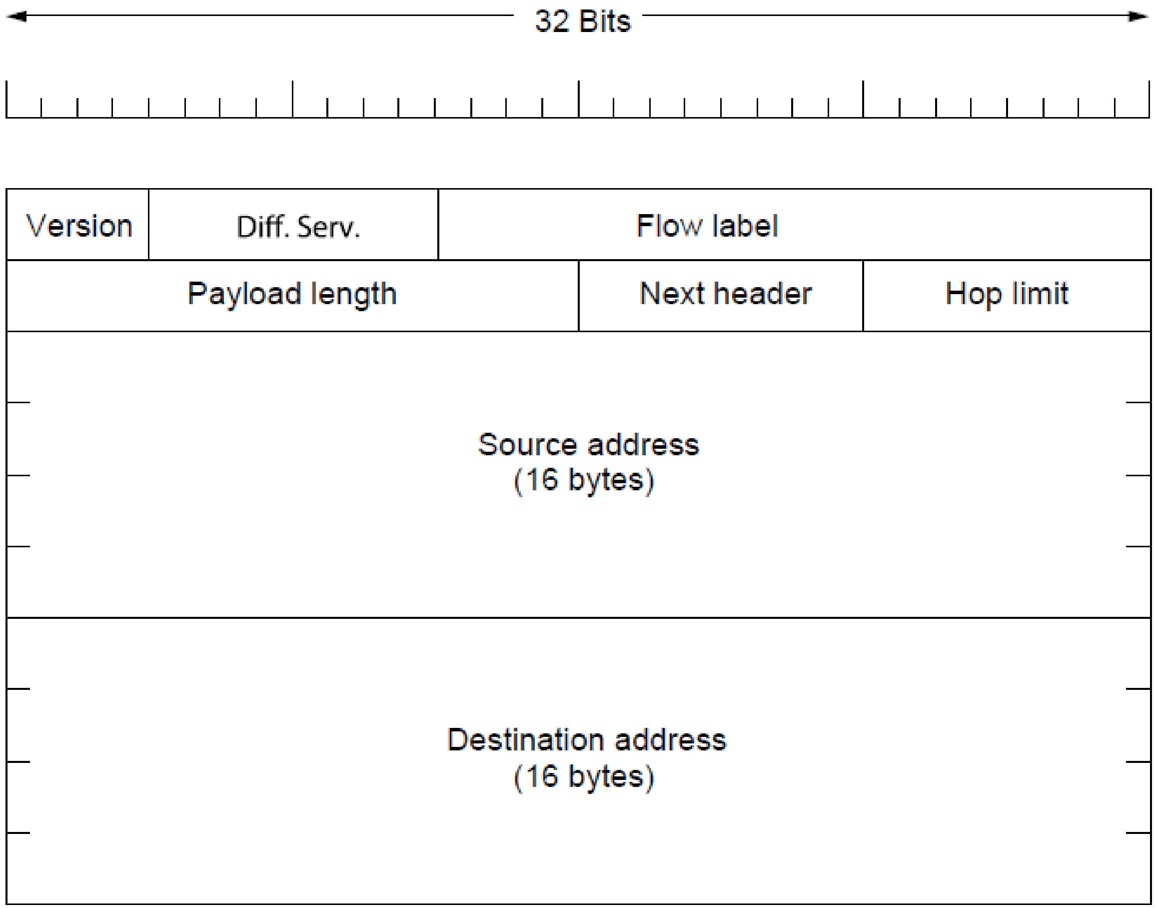


Placement and operation of a NAT box.

IP Version 6 Goals

- Support billions of hosts
- Reduce routing table size
- Simplify protocol
- Better security
- Attention to type of service
- Aid multicasting
- Roaming host without changing address
- Allow future protocol evolution
- Permit coexistence of old, new protocols. . .

IP Version 6



The IPv6 fixed header (required).

IP Version 6

Extension header	Description
Hop-by-hop options	Miscellaneous information for routers
Destination options	Additional information for the destination
Routing	Loose list of routers to visit
Fragmentation	Management of datagram fragments
Authentication	Verification of the sender's identity
Encrypted security payload	Information about the encrypted contents

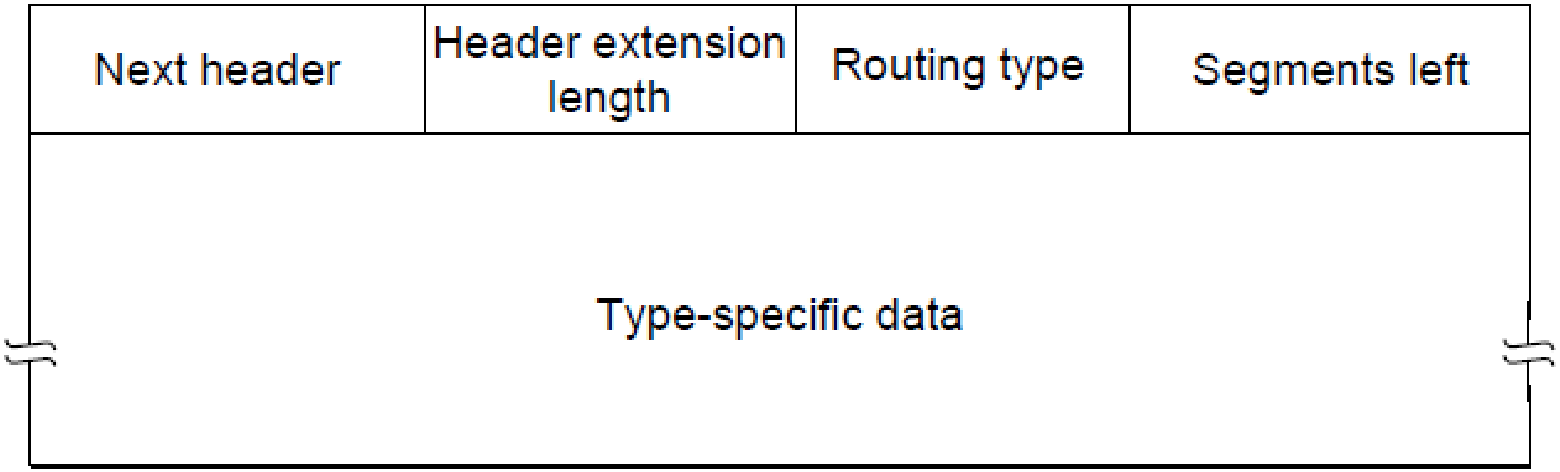
IPv6 extension headers

IP Version 6

Next header	0	194	4
Jumbo payload length			

The hop-by-hop extension header for large datagrams (jumbograms).

IP Version 6



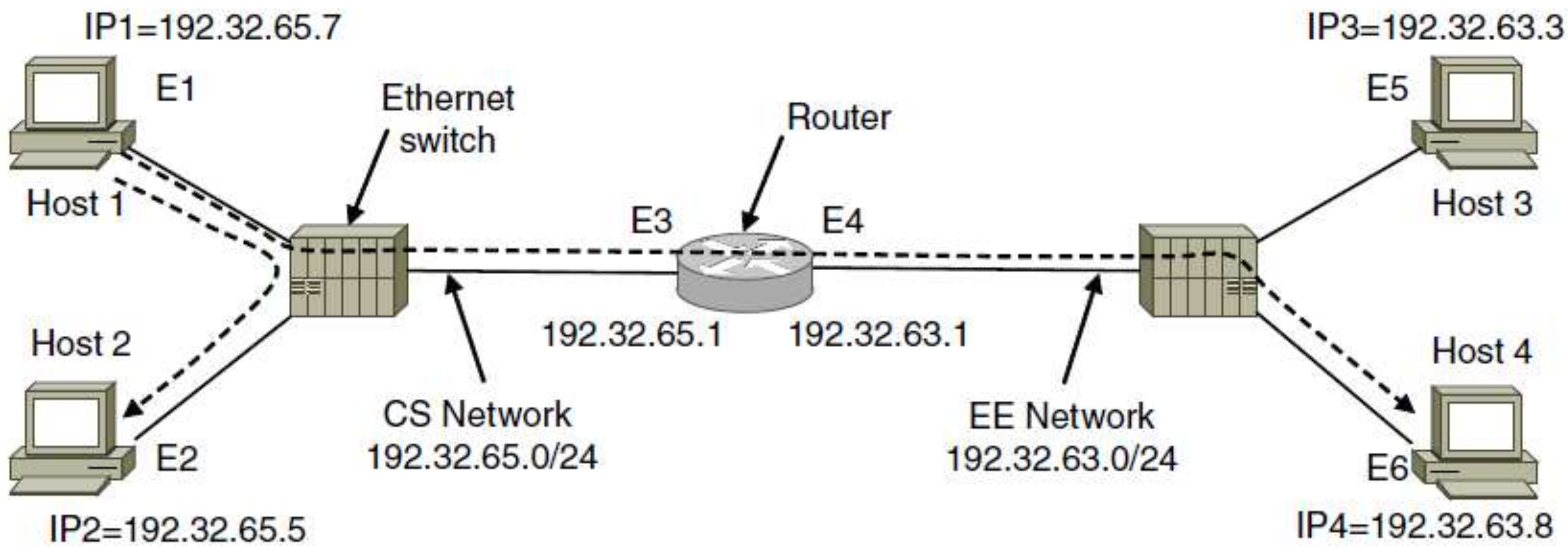
The extension header for routing.

Internet Control Protocols

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

The principal ICMP message types.

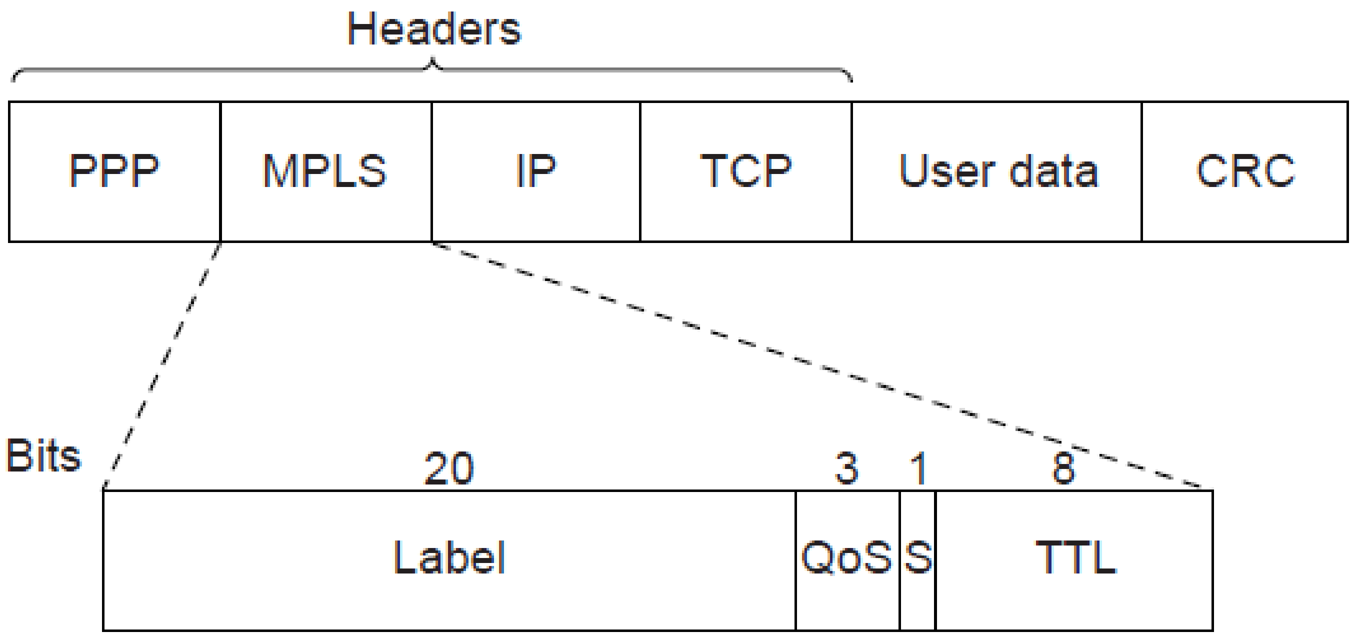
Internet Control Protocols



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

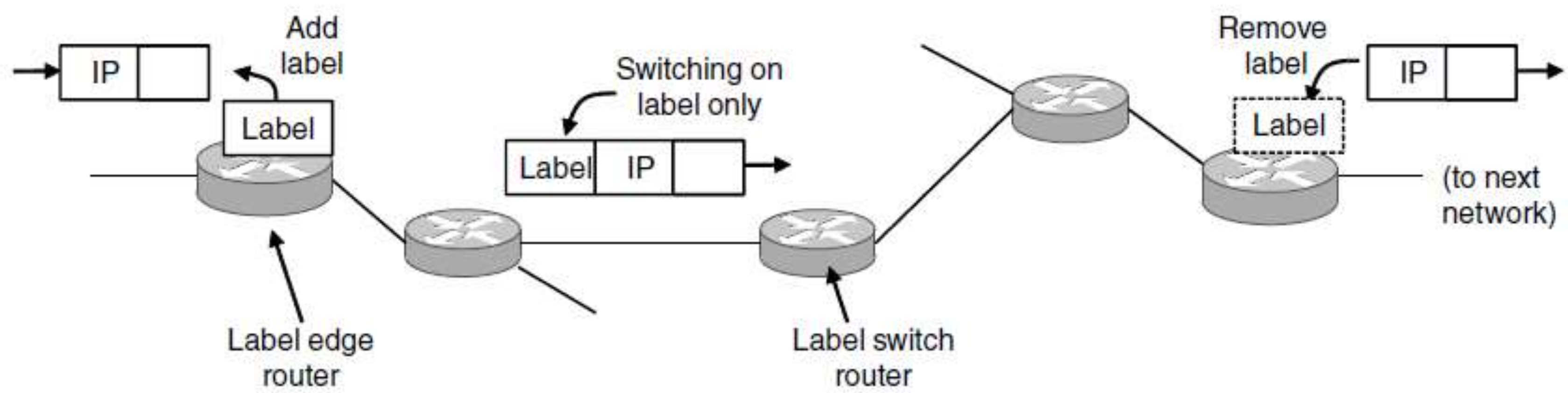
Two switched Ethernet LANs joined by a router

Label Switching and MPLS



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

Label Switching and MPLS



Forwarding an IP packet through an MPLS network

End

Chapter 5