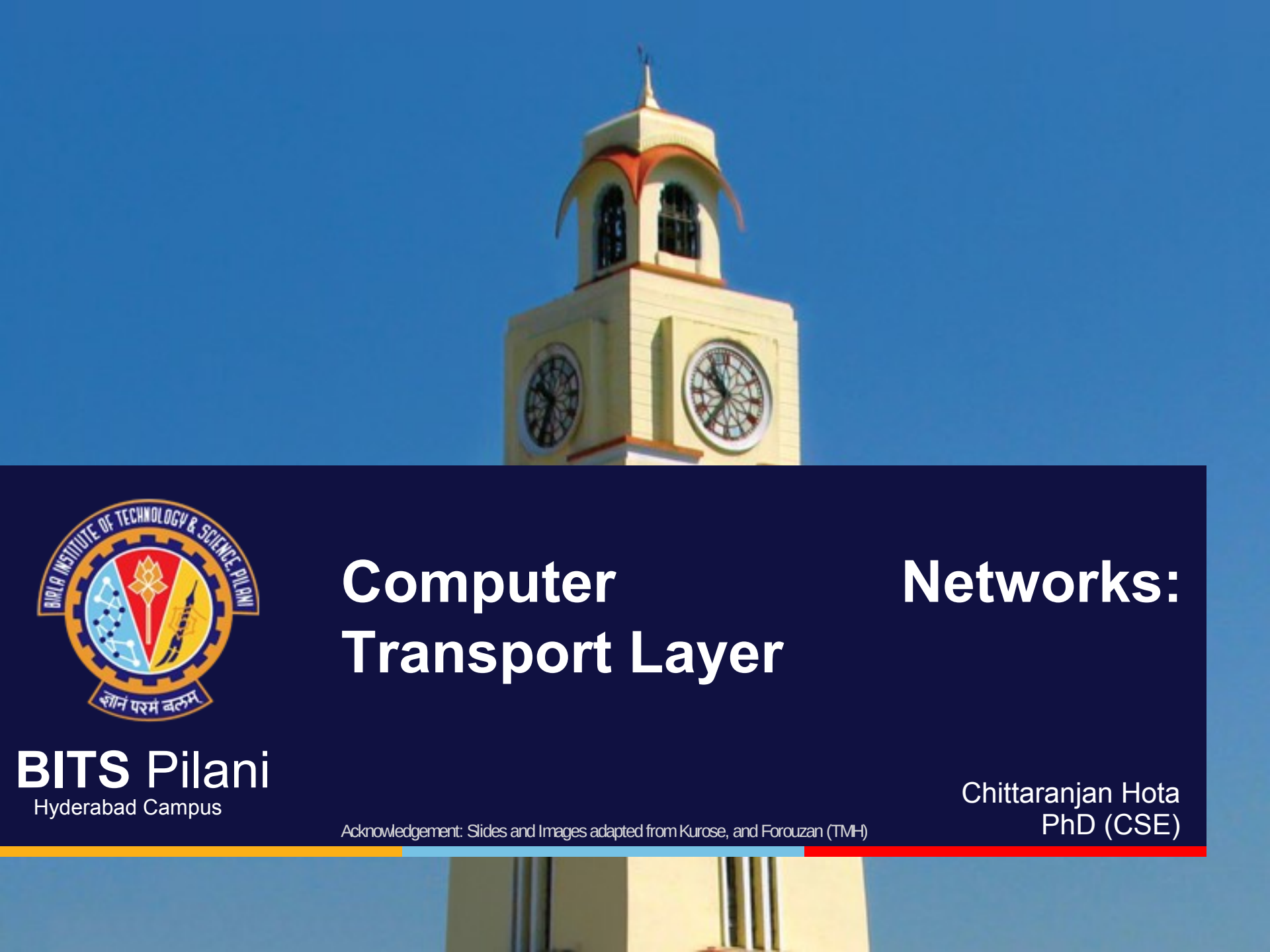


Computer Networks: Transport Layer

BITS Pilani
Hyderabad Campus

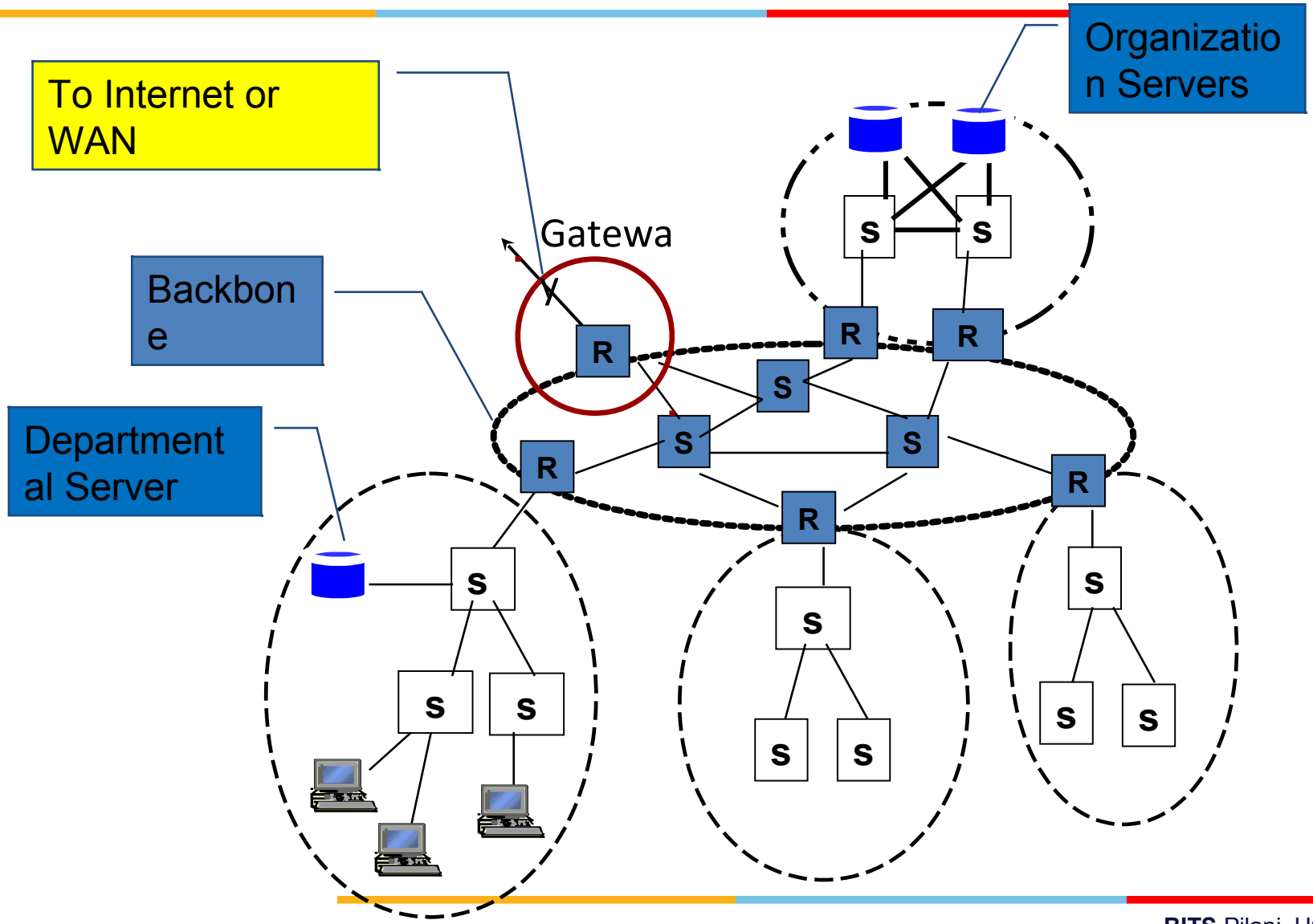
Chittaranjan Hota
PhD (CSE)

Acknowledgement: Slides and Images adapted from Kurose, and Forouzan (TMH)

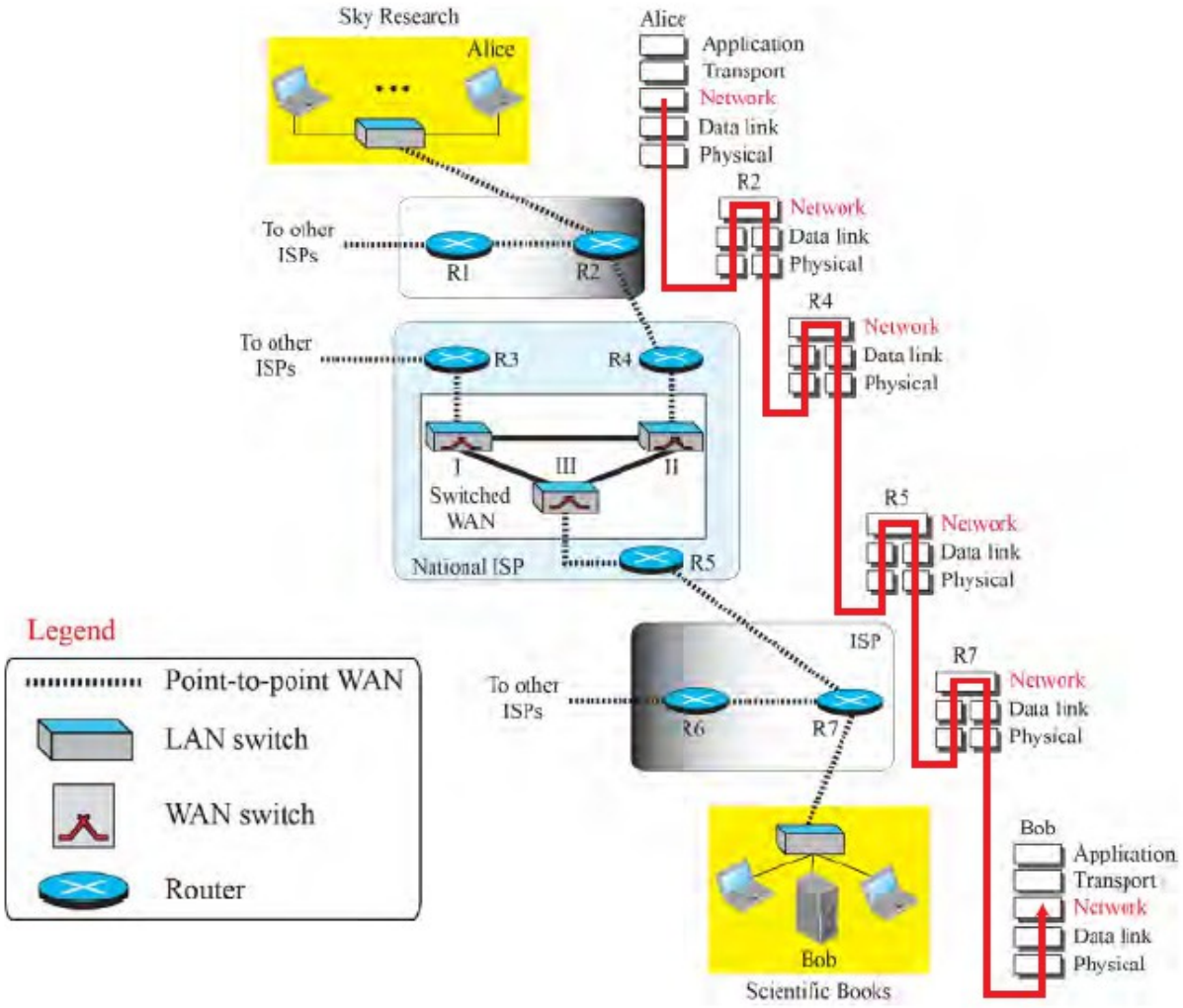
Network Layer

[Image sources: Behrouz Forouzan, Garcia, Tanenbaum]

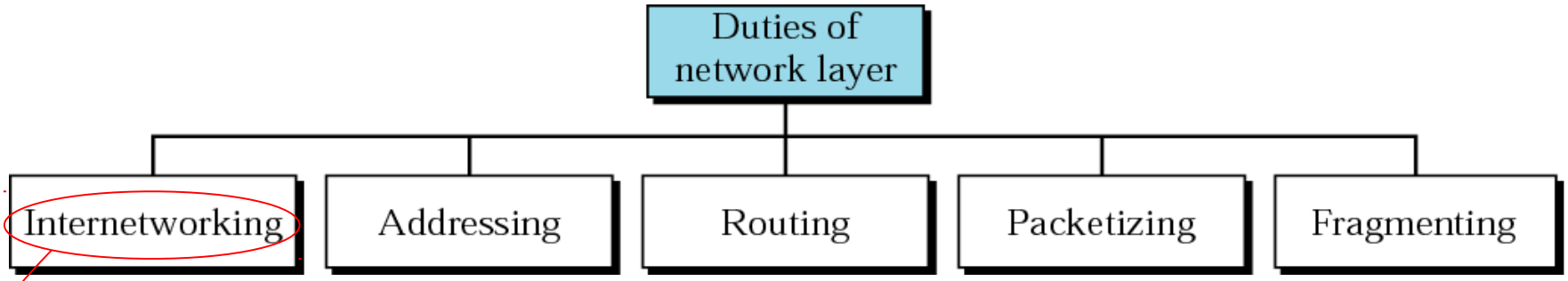
Metropolitan Area Network



Communication at the Network layer

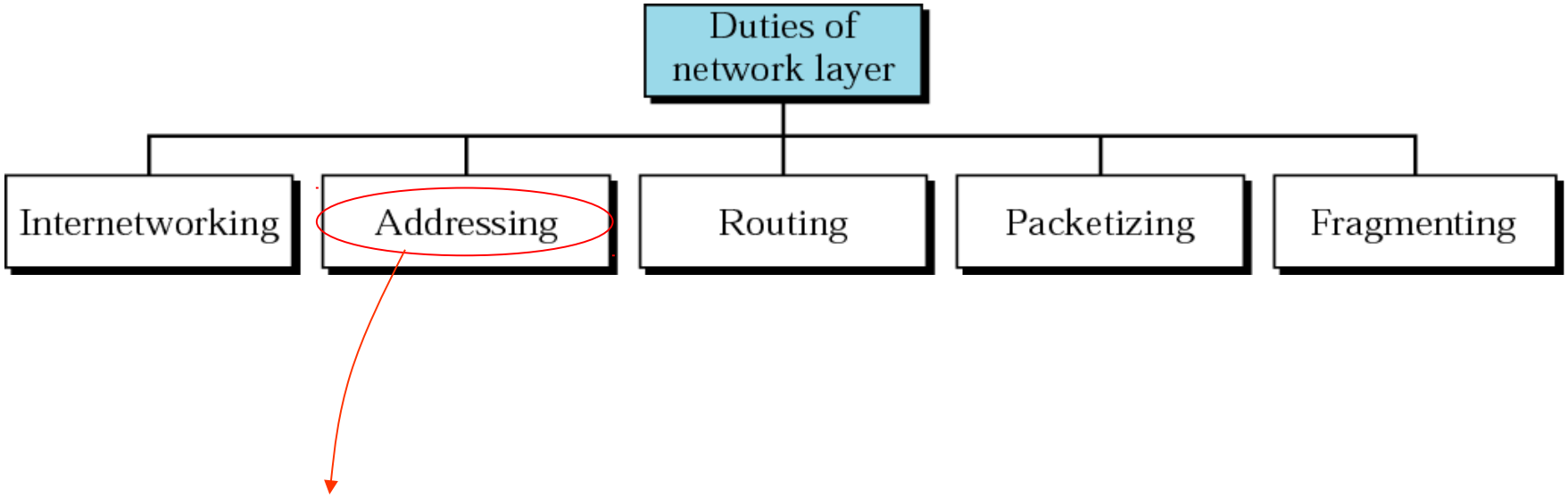


Functions of Network layer



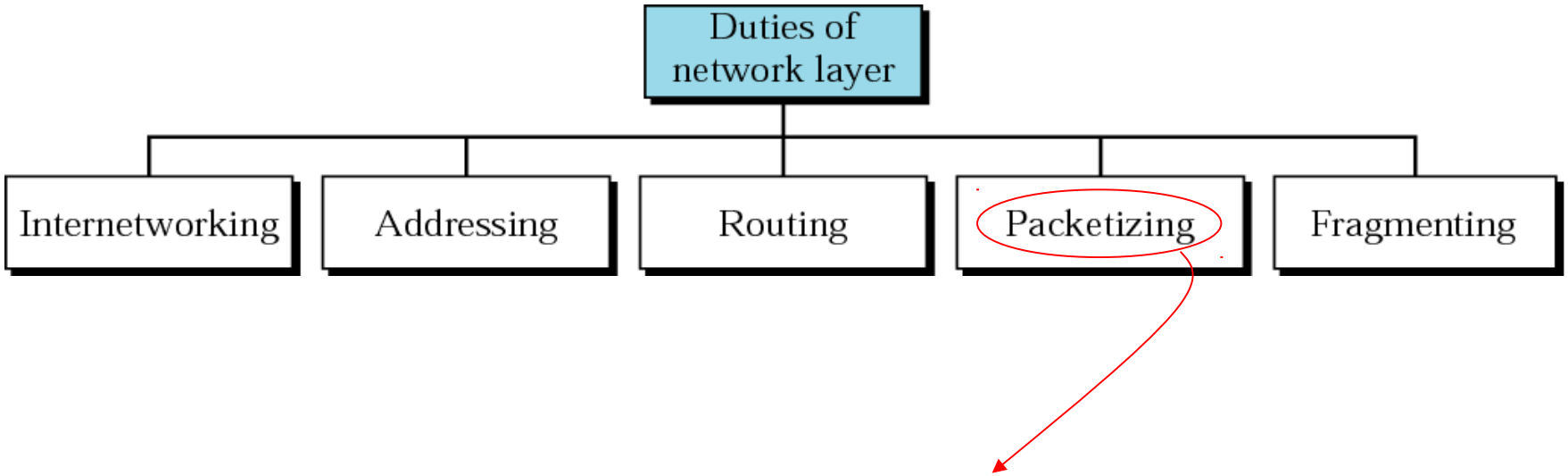
Interconnecting different networks (various LAN technologies, telephone network, satellite link, ATM networks etc.) and making them look the same to the transport layer.

Functions of Network layer



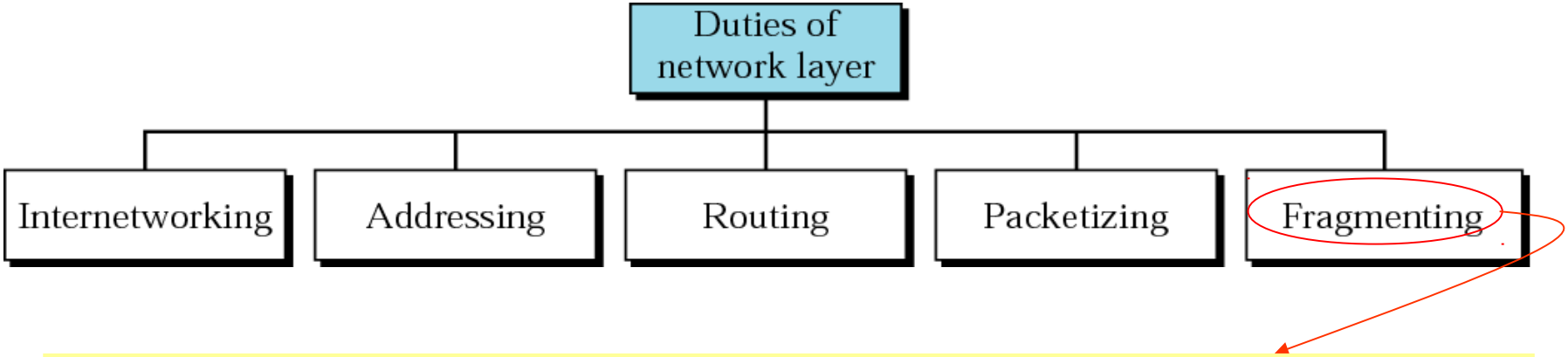
Unique addresses are required to define each host/machine/device/user in the network. We cannot use the data link layer addresses (Ethernet, HDLC, PPP etc.)!!

Functions of Network layer



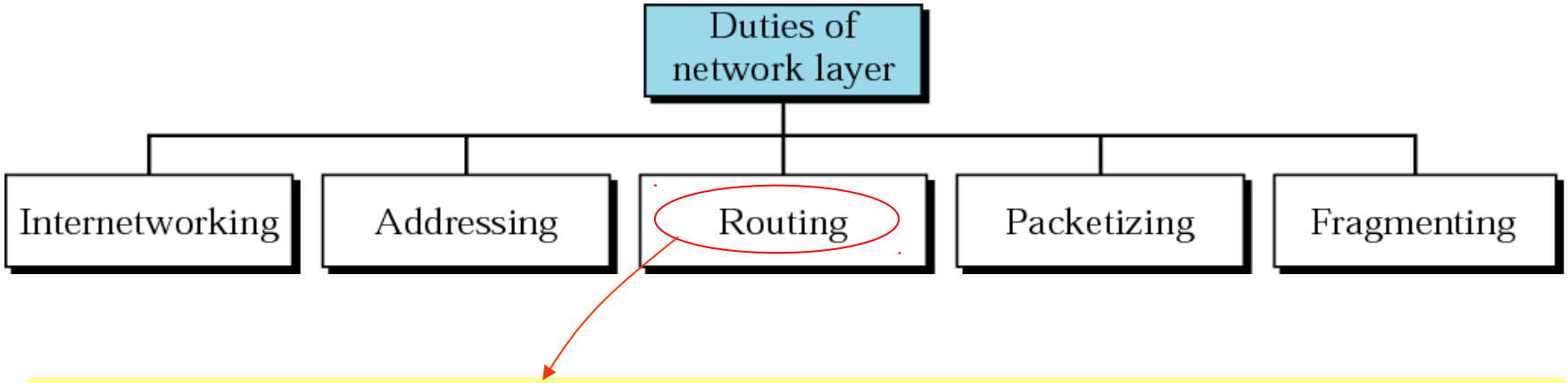
The Protocol Data Units (PDU's) coming from the transport layer must be placed in network-layer packets and sent to the data-link layer.

Functions of Network layer



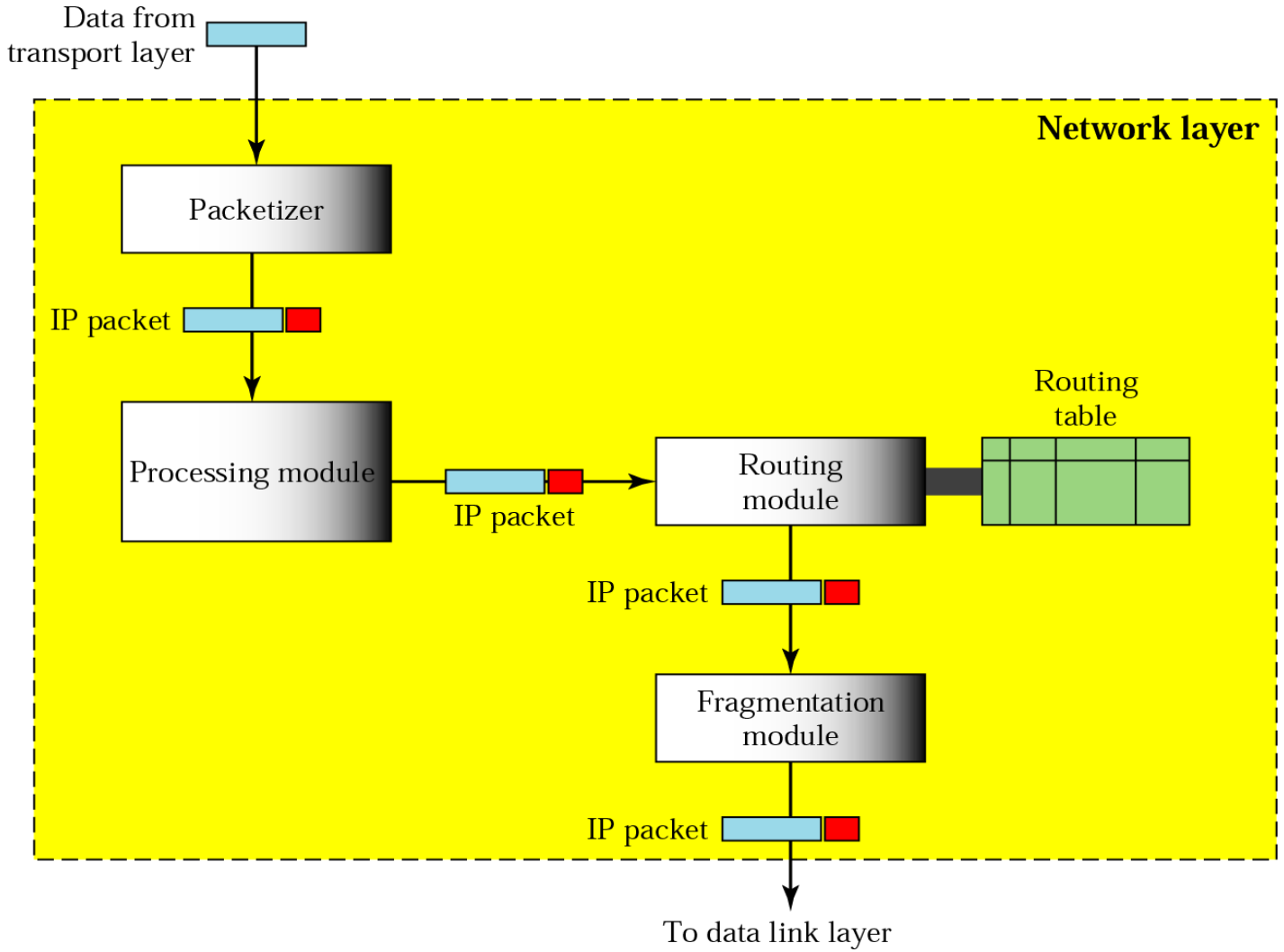
All Data link layer technologies can handle a different packet length. The network layer must be able to fragment transport layer PDUs into smaller units so that they can be transferred over various data-link layer technologies.

Functions of Network layer

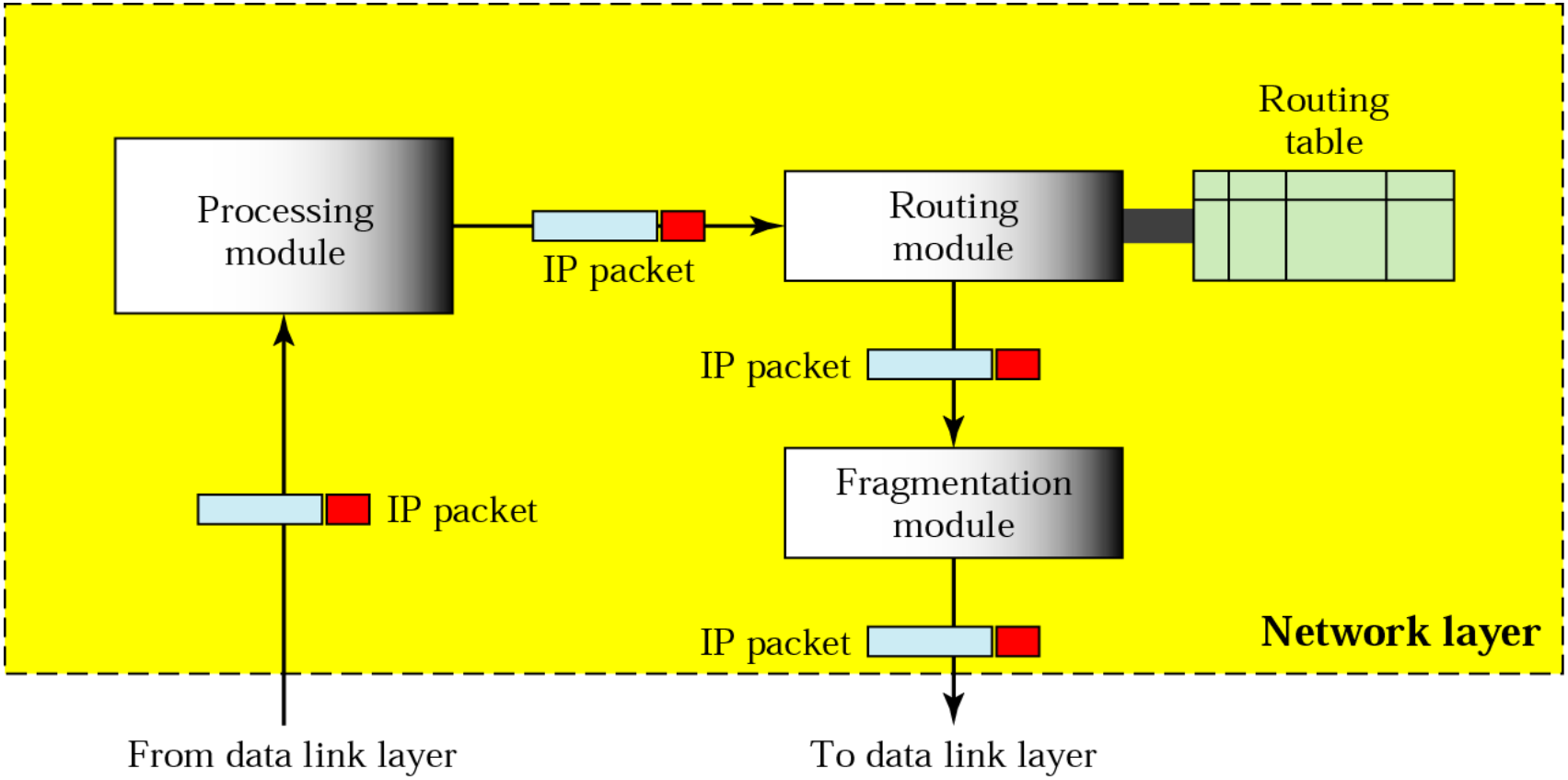


Now that you have your network layer packet, where do you send it ?

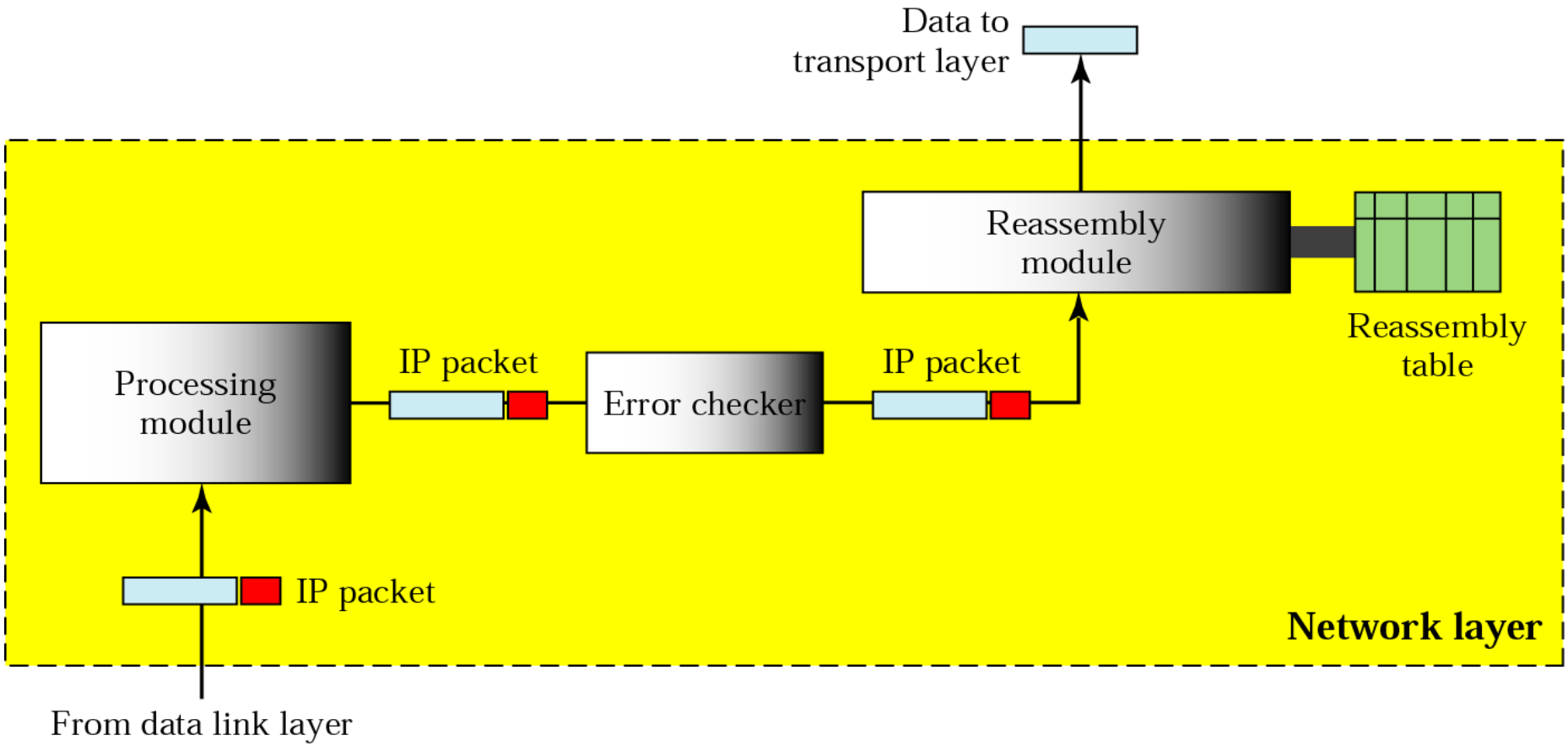
Network layer at the Source



Network layer at Router



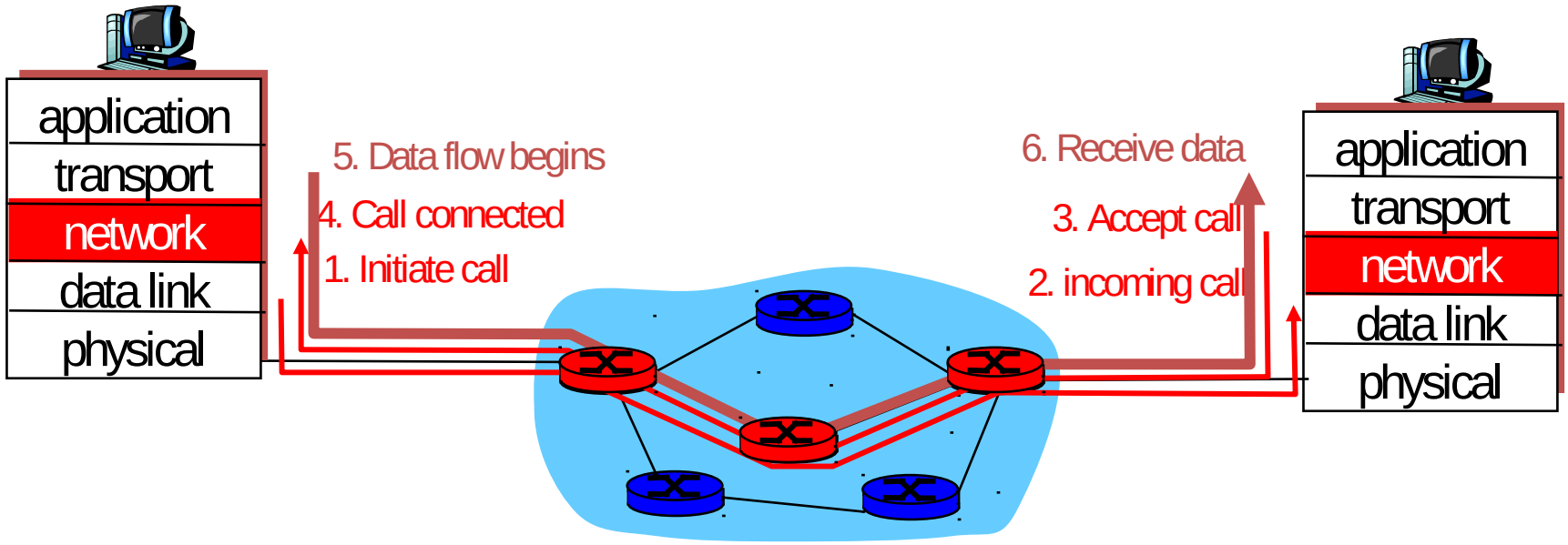
Network layer at the Destination



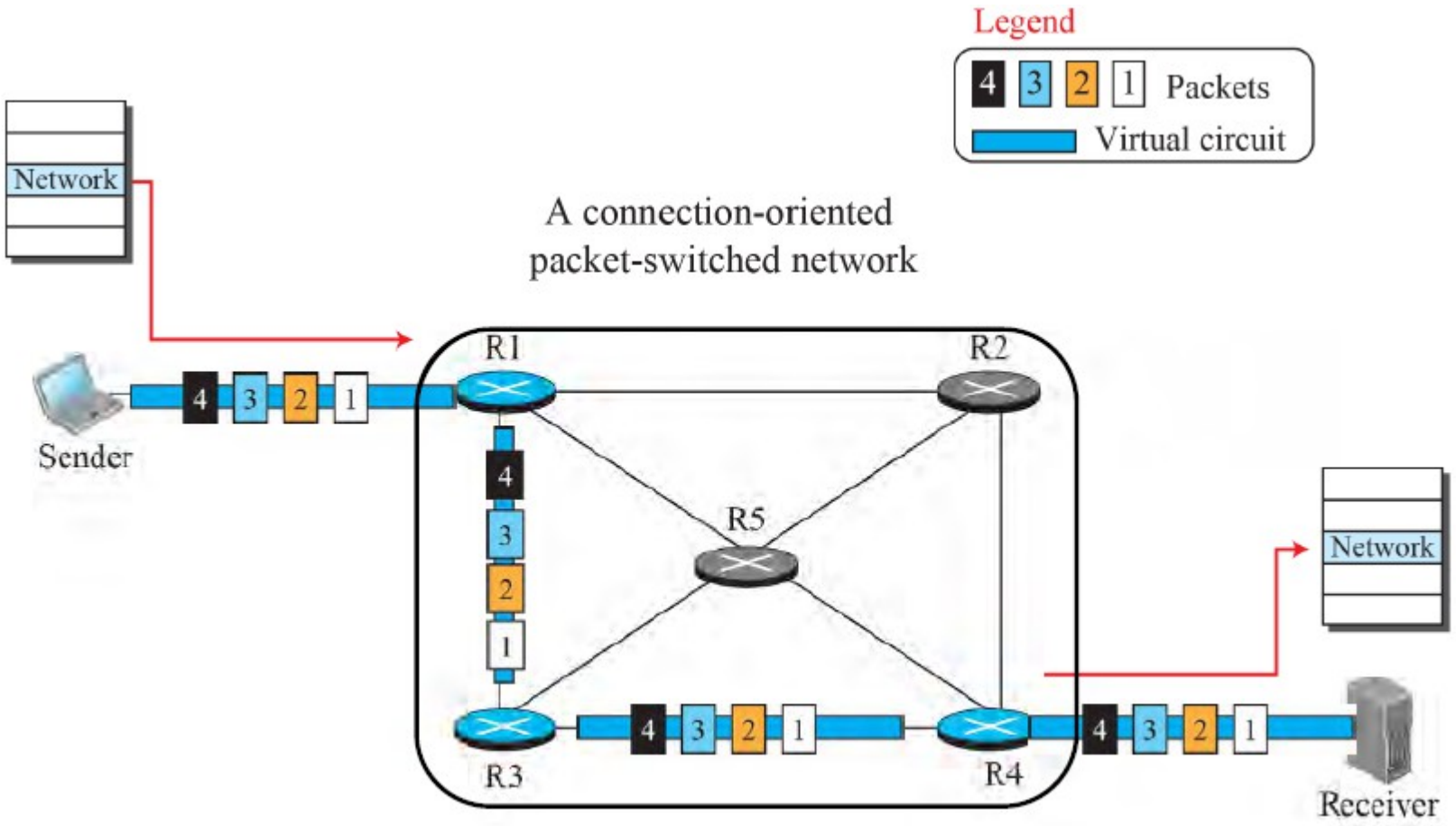
Network layer connection-oriented and connection-less service

- Datagram network provides network-layer connectionless service
- Virtual Circuit network provides network-layer connection-oriented service
- Analogous to the transport-layer services, but:
  - Service: host-to-host
  - No choice: network provides one or the other
  - Implementation: in the core

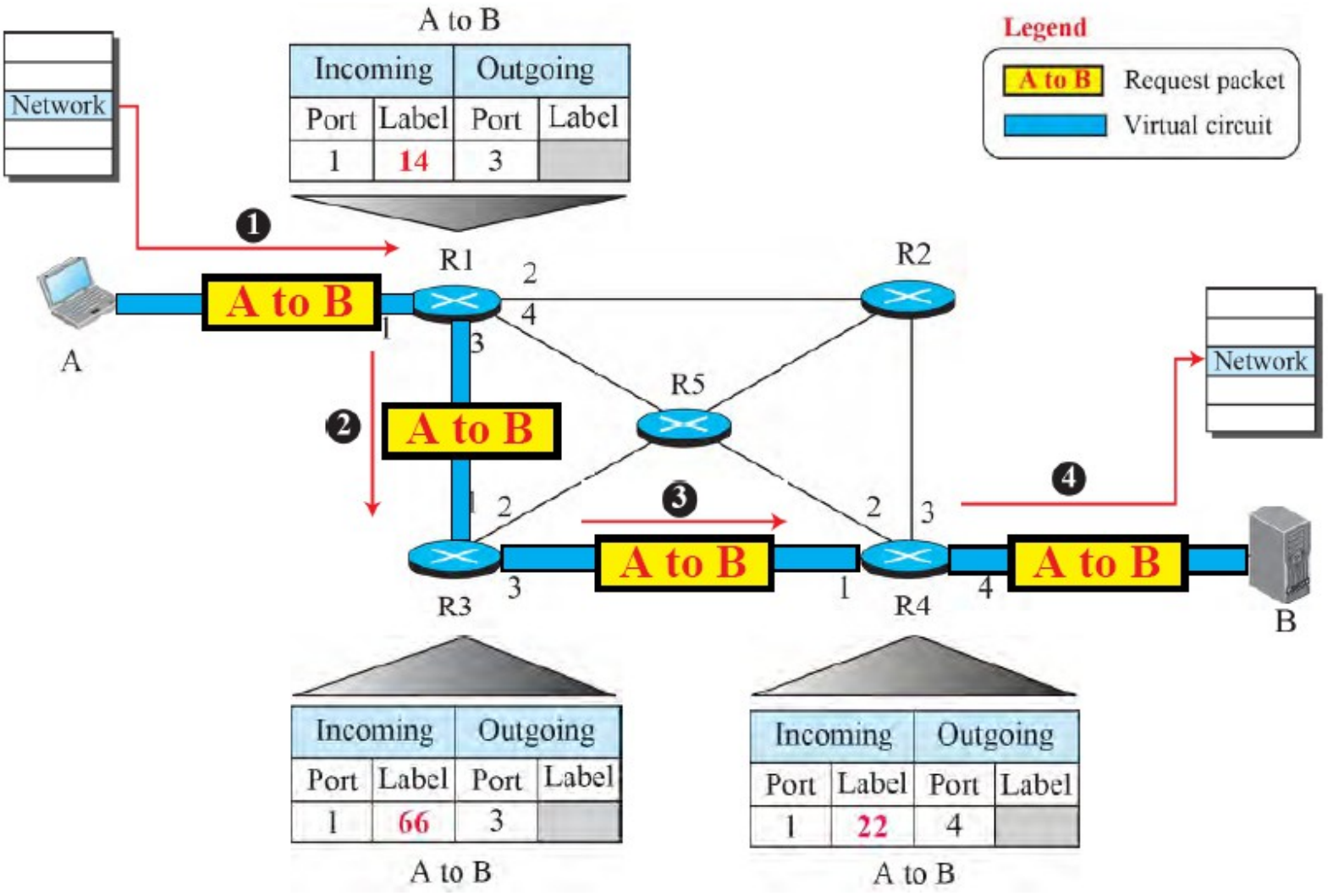
Virtual circuits: Signaling protocols



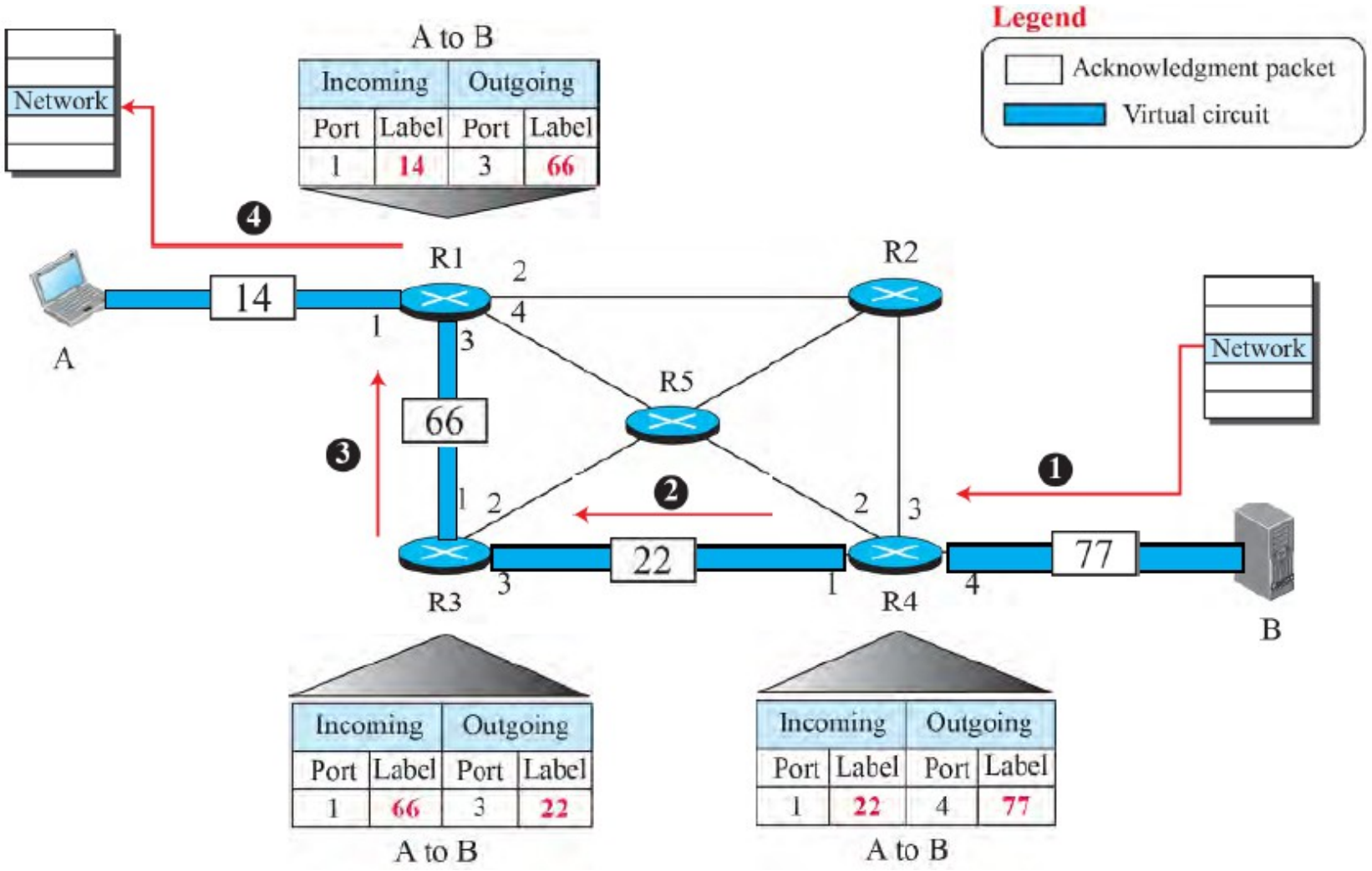
Virtual circuit packet switched n/w



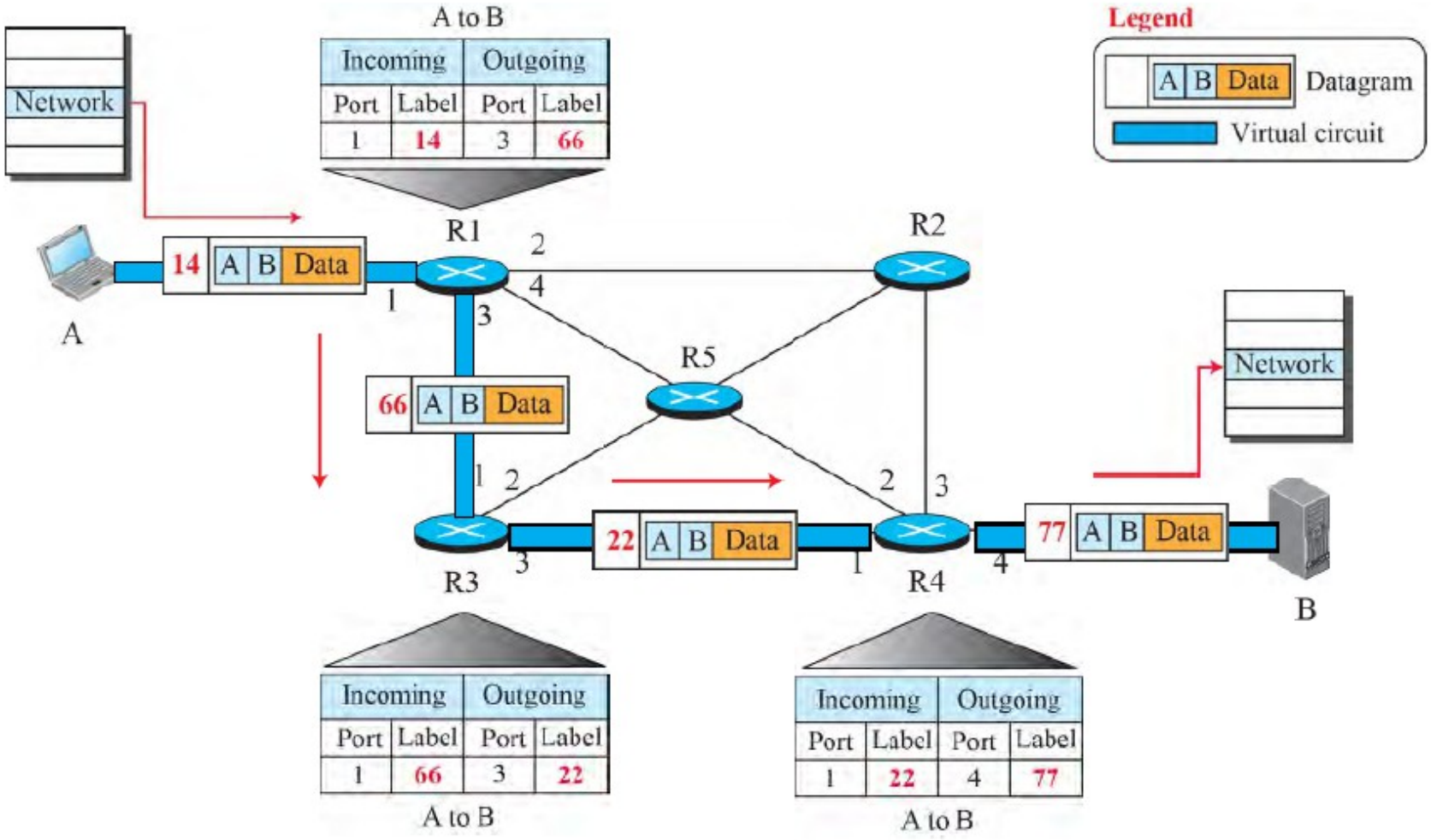
Virtual circuit: Sending Request packet



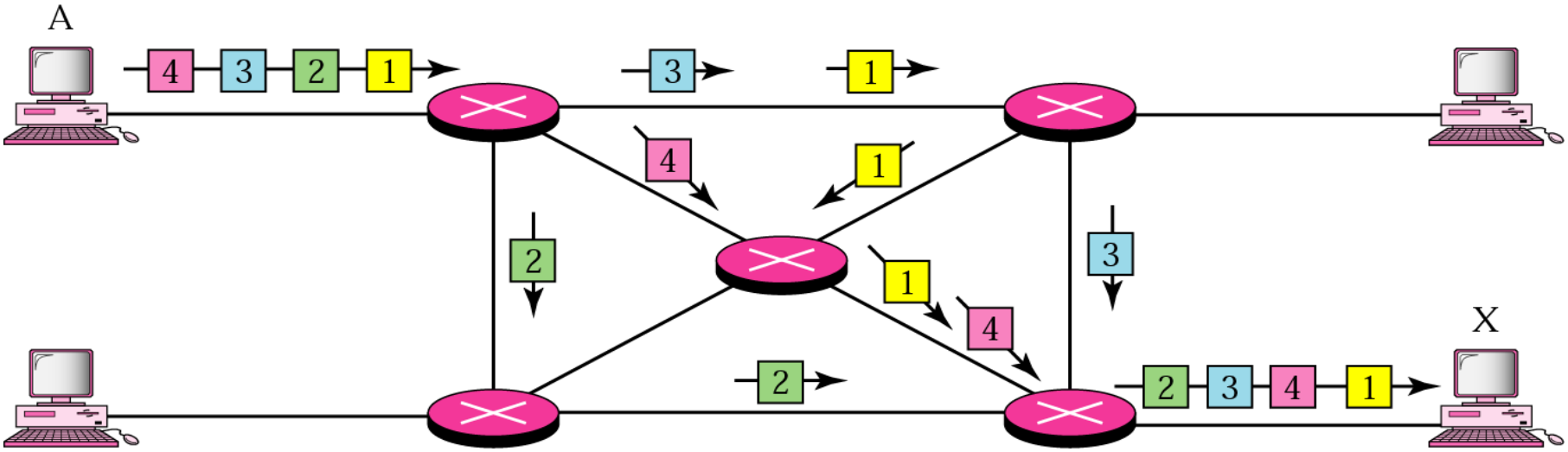
Virtual circuit: Sending Ack packet



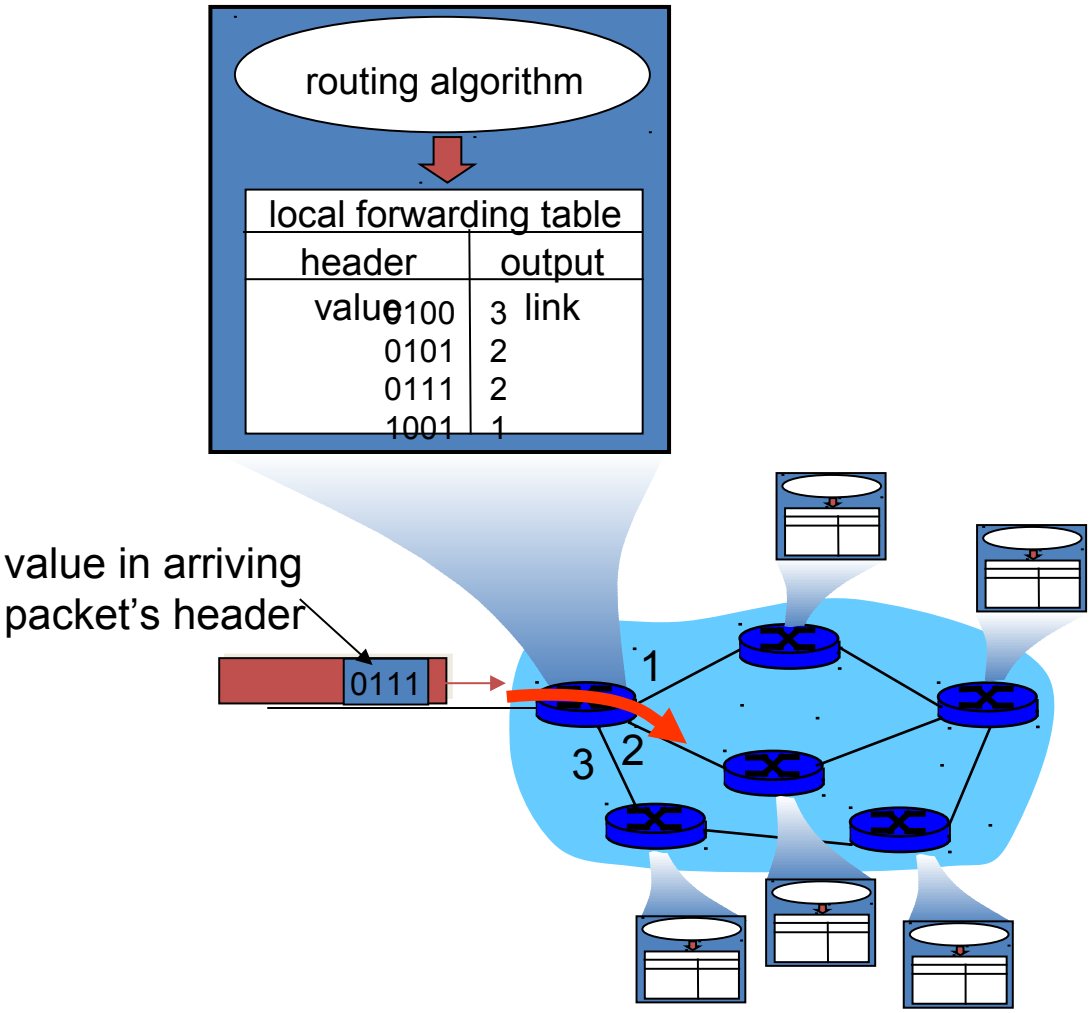
Virtual circuit: Data transfer



Datagram networks



Forwarding & Routing: Local vs Global



Forwarding table

4 billion
possible entries

Destination Address Range	Link Interface
11001000 00010111 00010000 00000000 through 11001000 00010111 00010111 11111111	0
11001000 00010111 00011000 00000000 through 11001000 00010111 00011000 11111111	1
11001000 00010111 00011001 00000000 through 11001000 00010111 00011111 11111111	2
otherwise	3

Longest prefix matching

innovate achieve lead

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

Examples

DA: 11001000 00010111 00010110 10100001 Which interface?

DA: 11001000 00010111 00011000 10101010 Which interface?

Longest prefix matching

innovate achieve lead

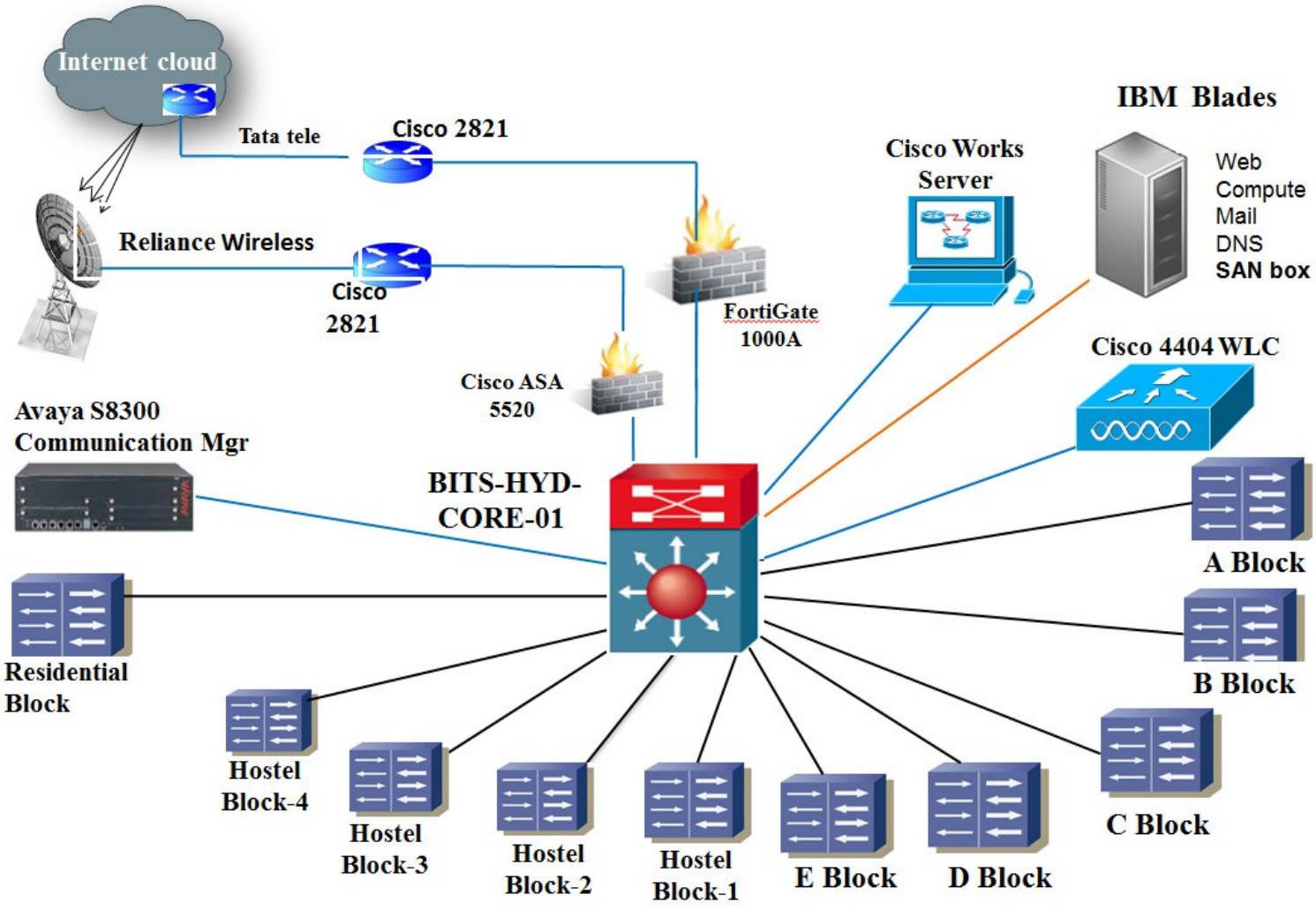
Prefix Match	Link Interface
11001000 00010111 00010	0
11001000 00010111 00011000	1
11001000 00010111 00011	2
otherwise	3

Examples

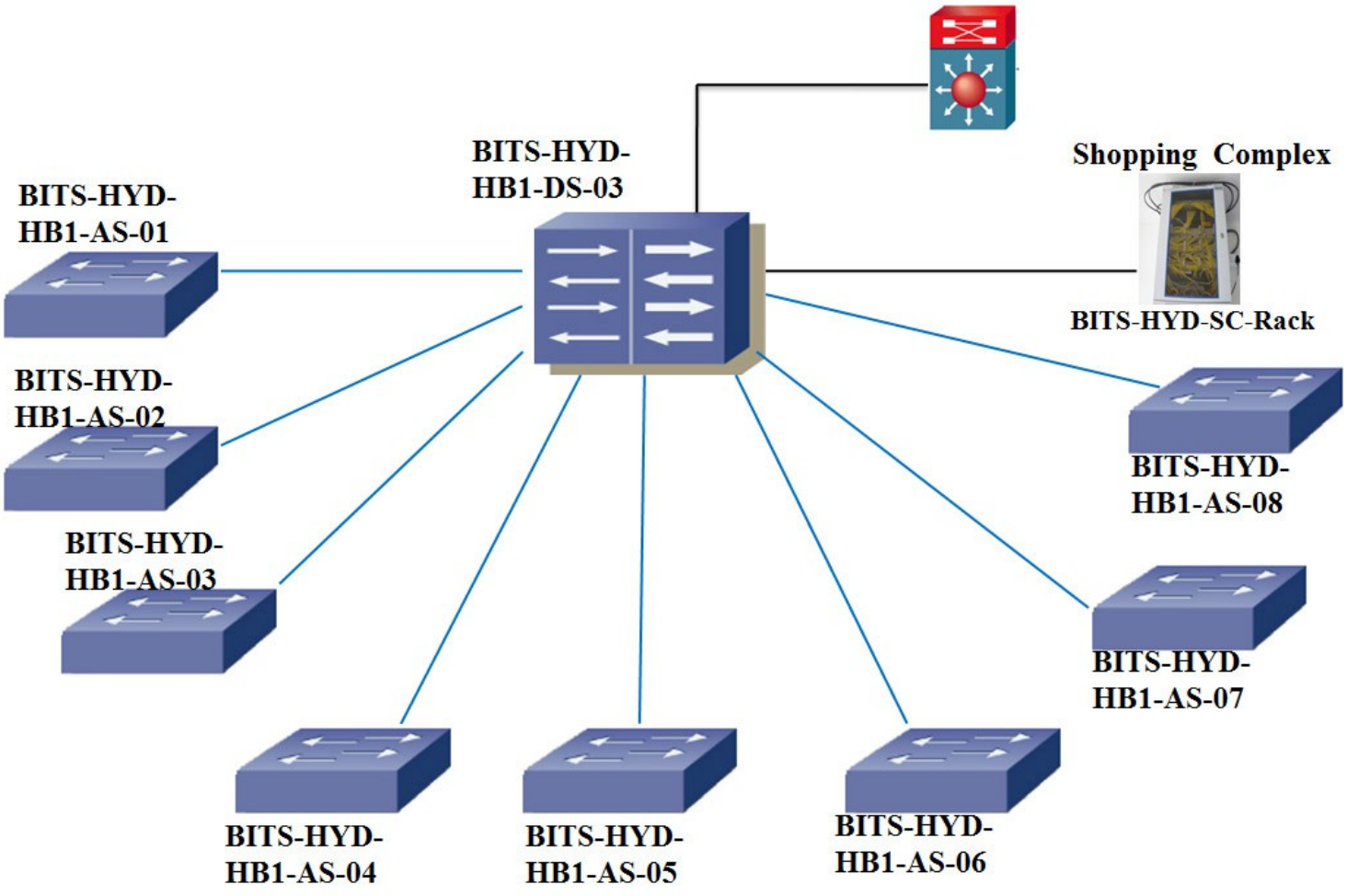
DA: 11001000 00010111 00010110 10100001 Which interface?

DA: 11001000 00010111 00011000 10101010 Which interface?

BITS Hyderabad Campus Back Bone



Network Connectivity in Hostel Block - 1



Cisco Router 2821 @ BITS Hyderabad

innovate achieve lead

```
nterface GigabitEthernet0/0
description ********** TaTa connection **********
bandwidth 45000
ip address 111.93.6.70 255.255.255.252
duplex auto
speed 100
service-policy input bw-allocate_in
service-policy output bw-allocate

nterface GigabitEthernet0/1
description ********** firwall connection **********
bandwidth 45000
ip address 111.93.5.193 255.255.255.224
ip route-cache flow
duplex auto
speed auto

nterface Serial0/0/0
no ip address
shutdown
clock rate 2000000

nterface Serial0/0/1
no ip address
shutdown
clock rate 2000000

p classless
p route 0.0.0.0 0.0.0.0 111.93.6.69
```

```
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is 111.93.6.69 to network 0.0.0.0

     111.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
C       111.93.6.68/30 is directly connected, GigabitEthernet0/0
C       111.93.5.192/27 is directly connected, GigabitEthernet0/1
S*   0.0.0.0/0 [1/0] via 111.93.6.69
```

Routing at Distribution switch for Staff Quarters @ BITS Hyd

innovate achieve lead

```
      Welcome to Residential BLock Distribution Switch
==================================================


User Access Verification

Password:
BITS-HYD-RB-DS-07>en
Password:
BITS-HYD-RB-DS-07#sh ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is 172.16.100.1 to network 0.0.0.0

     172.16.0.0/16 is variably subnetted, 3 subnets, 2 masks
C       172.16.255.0/24 is directly connected, Vlan1
C       172.16.40.0/24 is directly connected, Vlan40
C       172.16.100.0/22 is directly connected, Vlan100
S*   0.0.0.0/0 [1/0] via 172.16.100.1
BITS-HYD-RB-DS-07# _
```

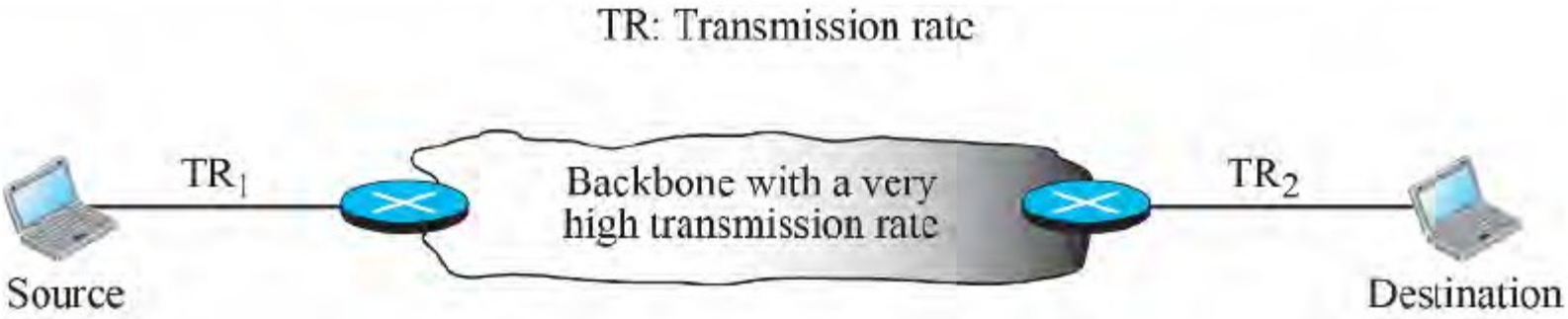
Performance Metrics

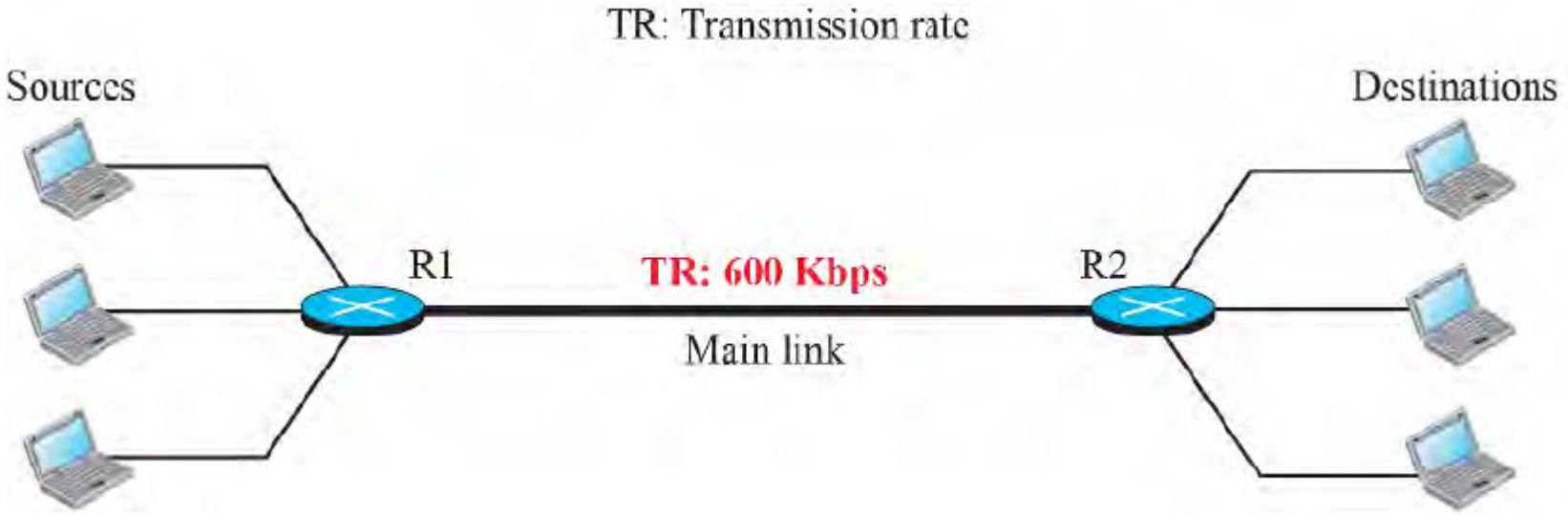
- Delay, Throughput, Packet loss

a. A path through three links

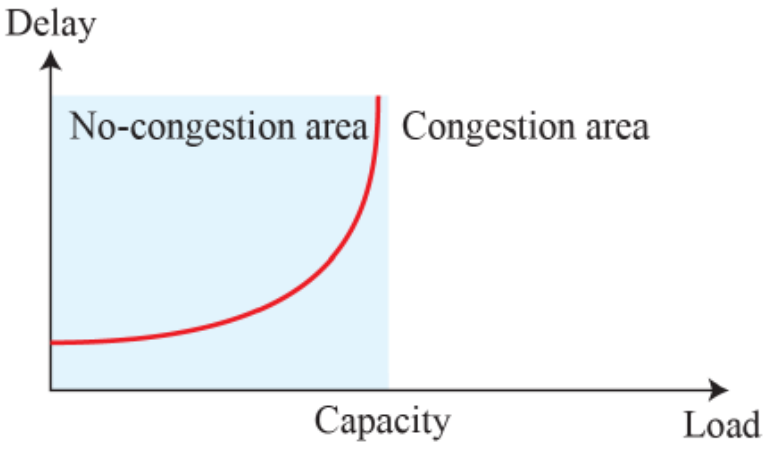
b. Simulation using pipes

Performance Metrics continued…

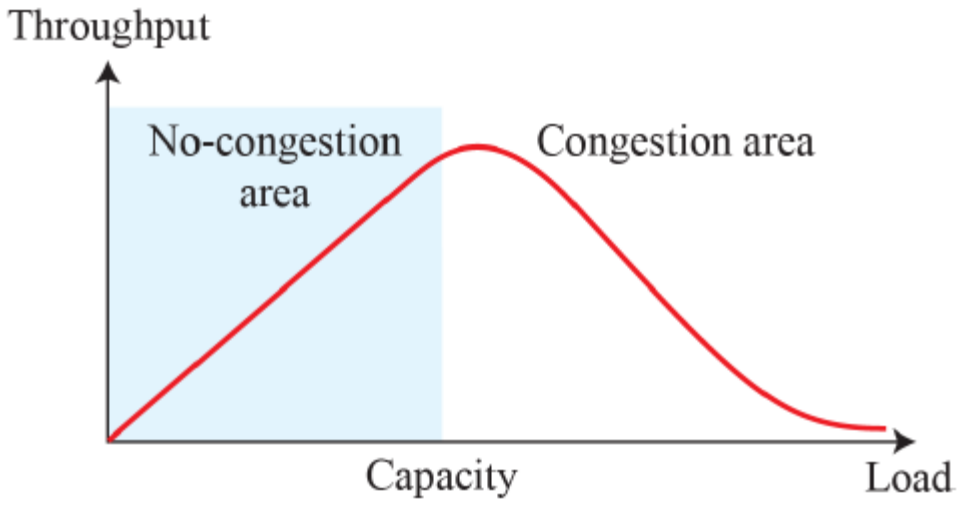




Effect on Performance



a. Delay as a function of load

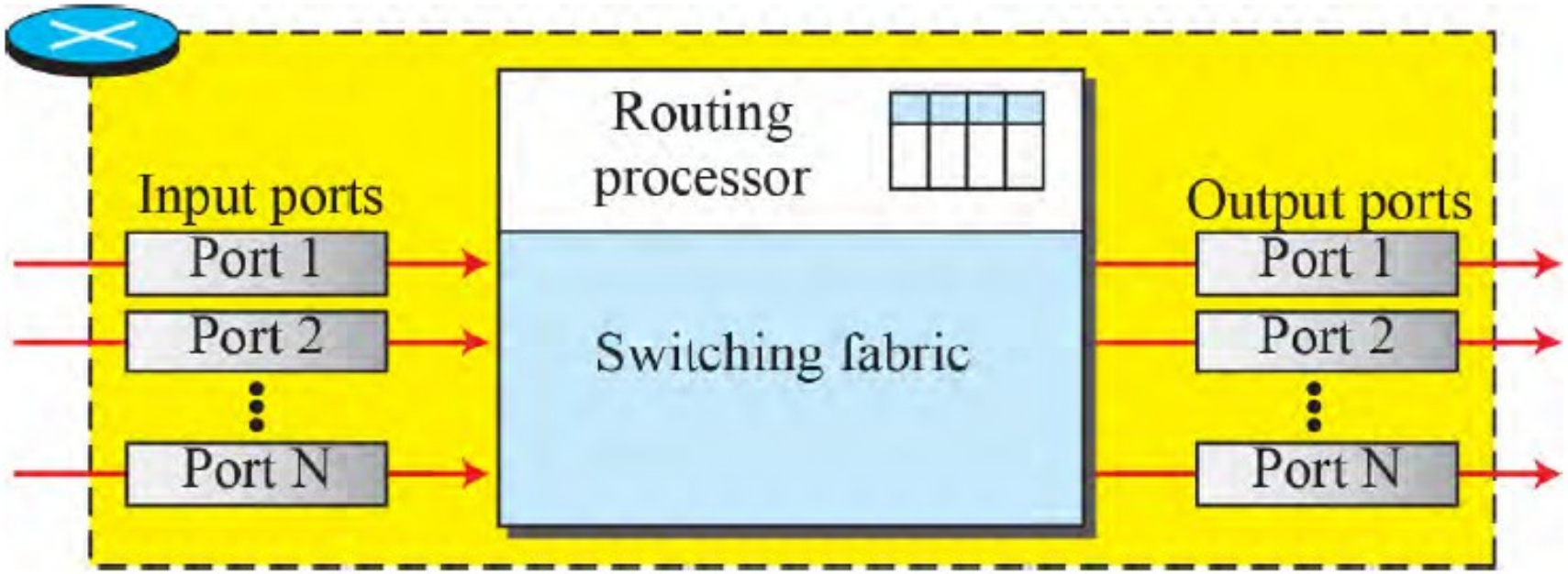


b. Throughput as a function of load

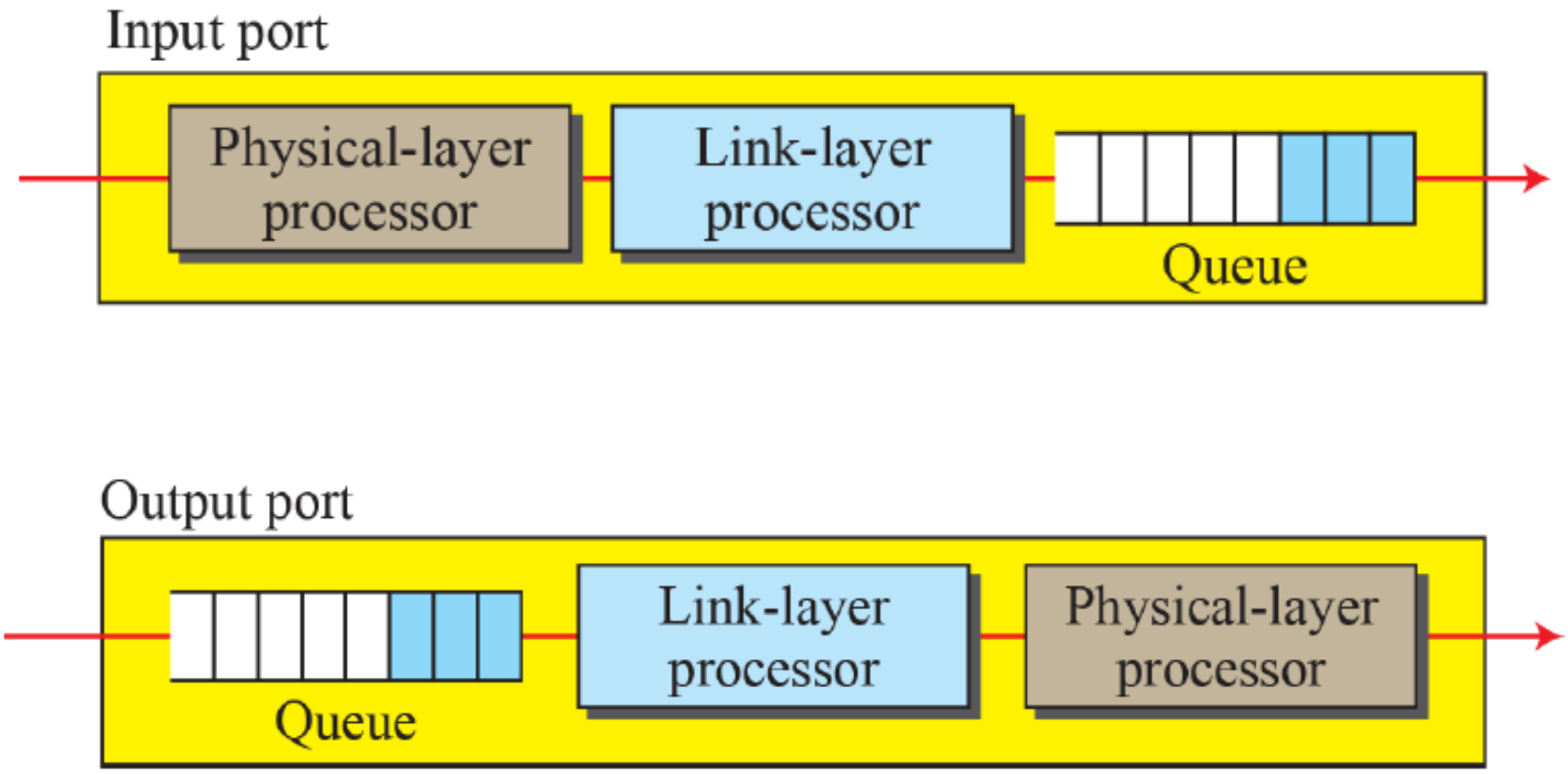
Router Architecture Overview

Two key router functions:

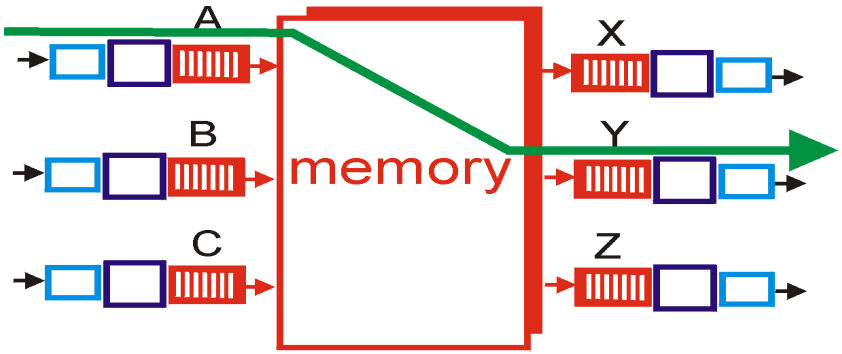
- run routing algorithms/protocol (RIP, OSPF, BGP)
- *forwarding* datagrams from incoming to outgoing link



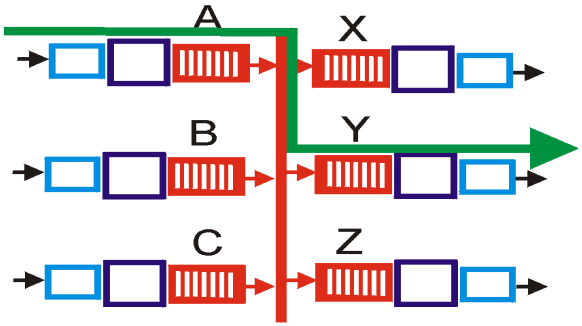
Continued…


Input port
Physical-layer processor
Link-layer processor
Queue
Output port
Queue
Link-layer processor
Physical-layer processor

Three types of switching fabrics

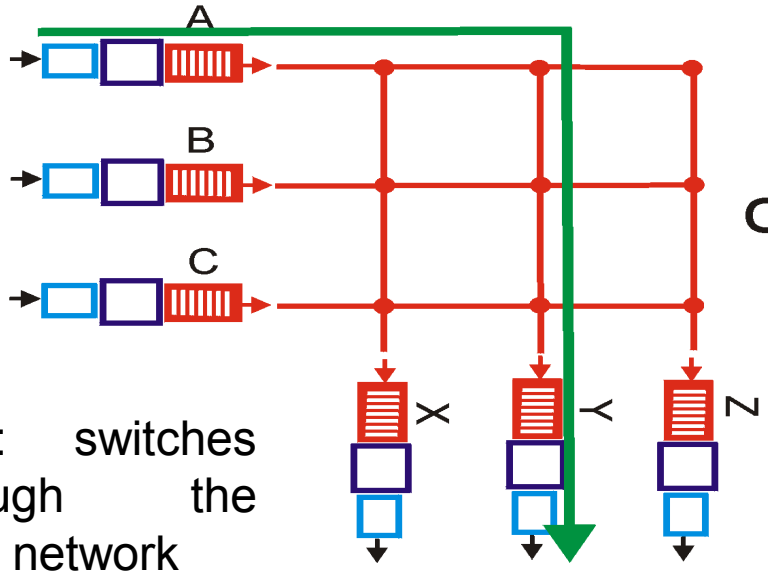


memory



bus

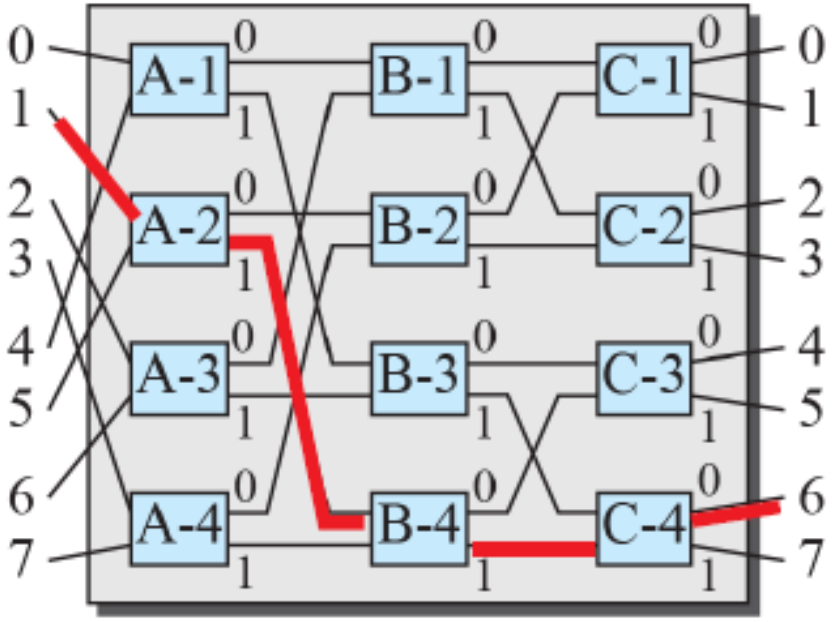
1 Gb/s bus in Cisco 1900: sufficient speed for access and enterprise routers (not regional or backbone)



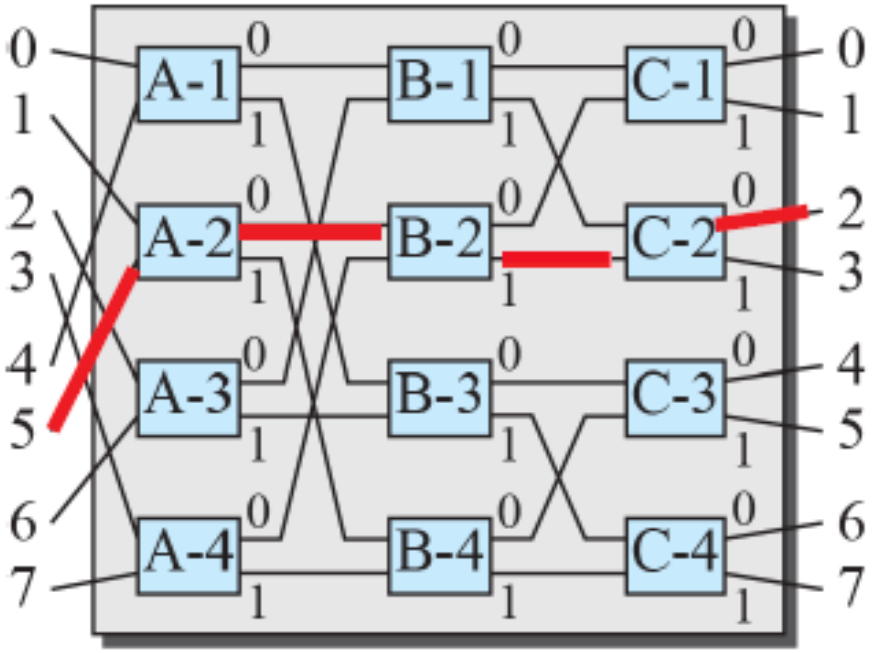
crossbar

Cisco 12000: switches Gb/s through the interconnection network

Routing in a banyan switch

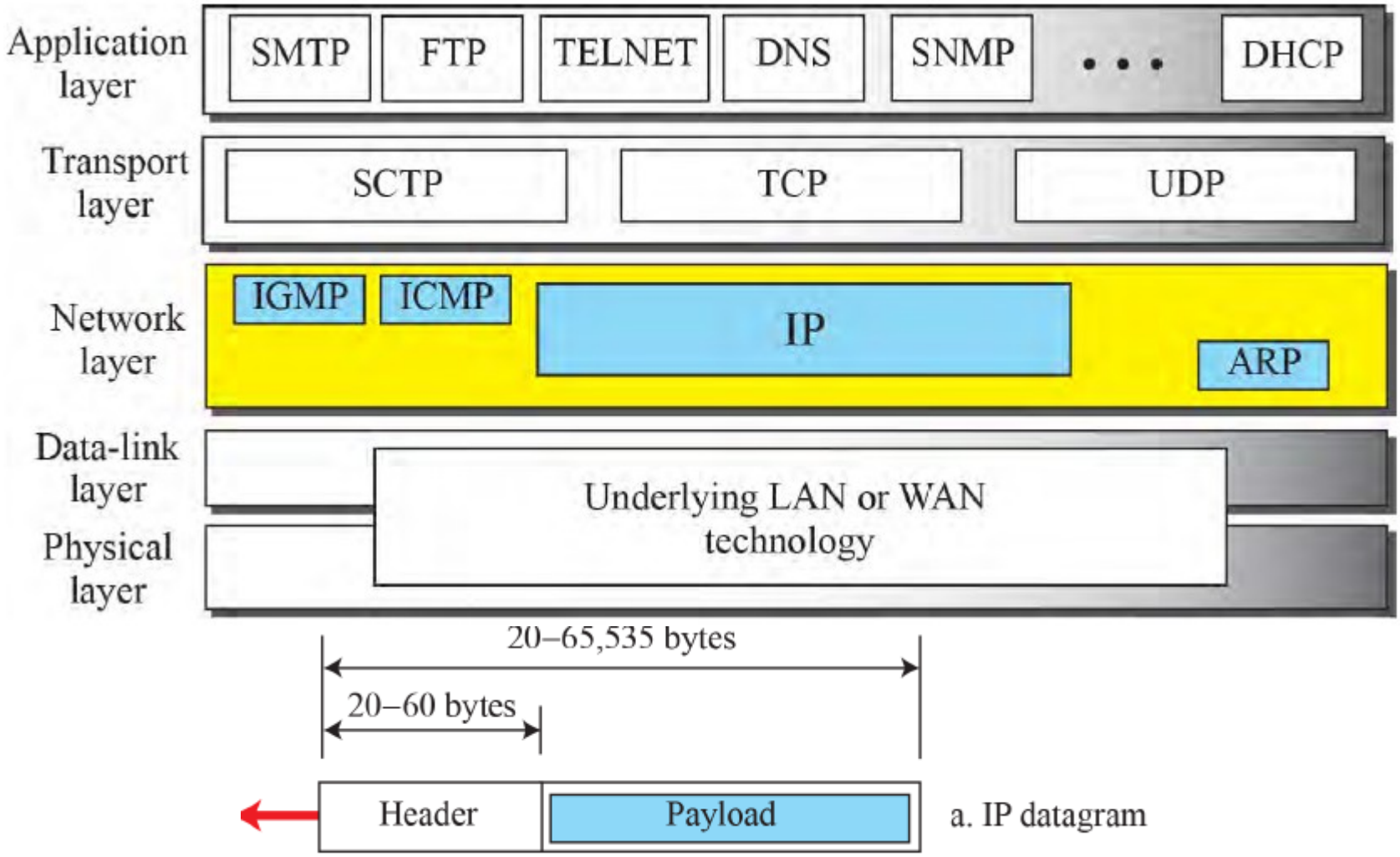


a. Input 1 sending to output 6 (110)

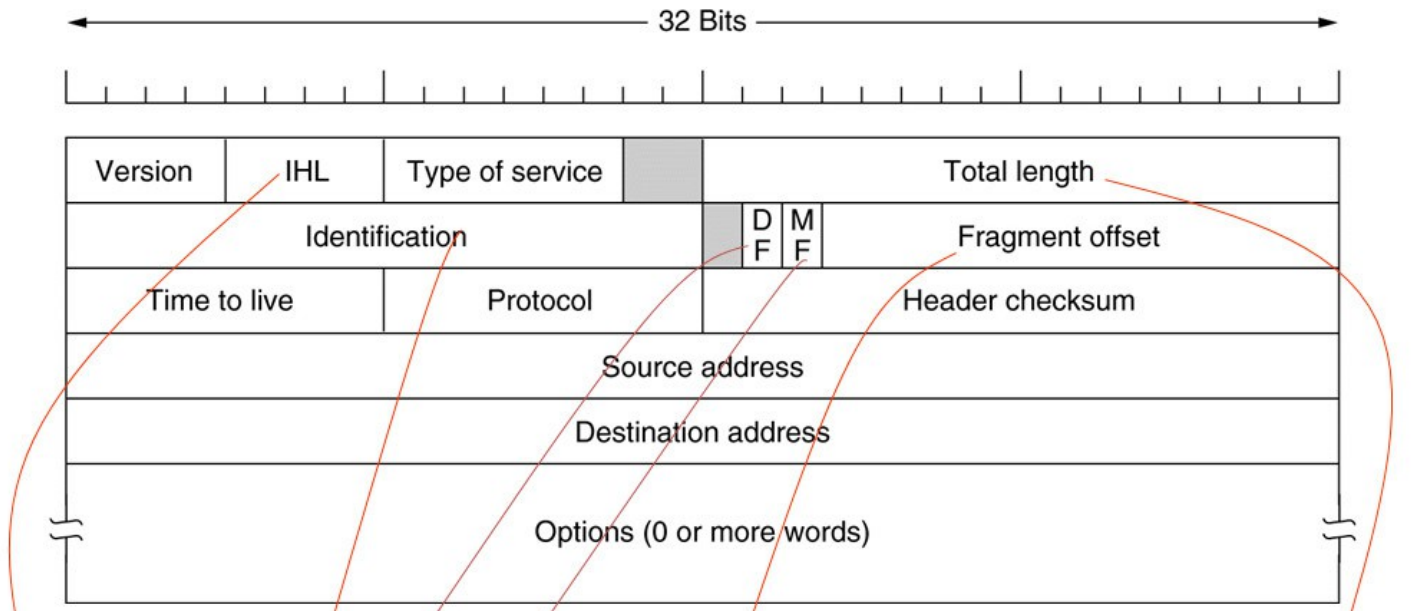


b. Input 5 sending to output 2 (010)

The Internet's Network layer

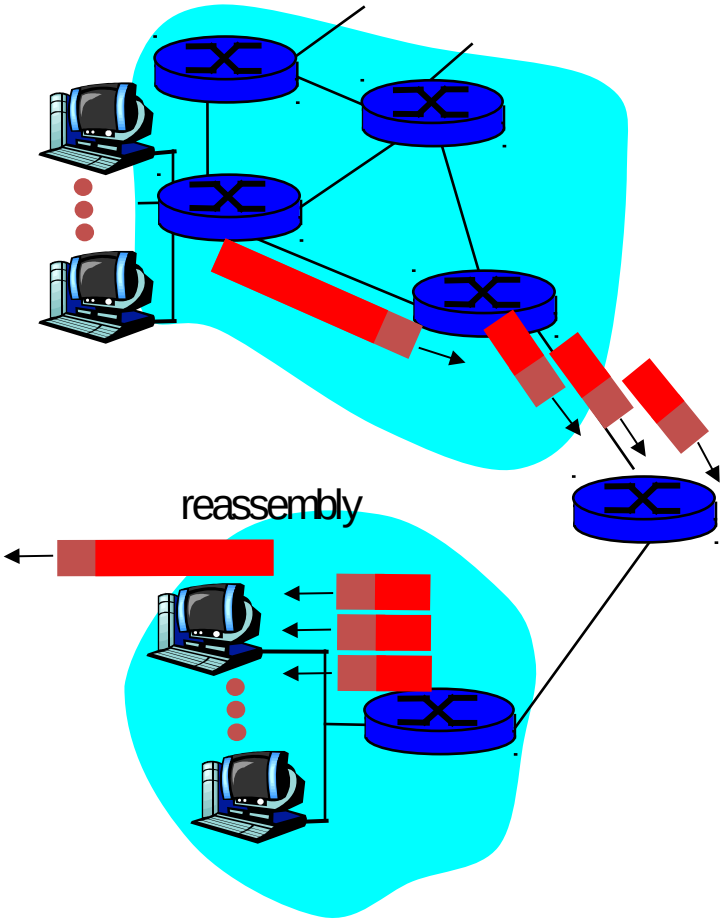


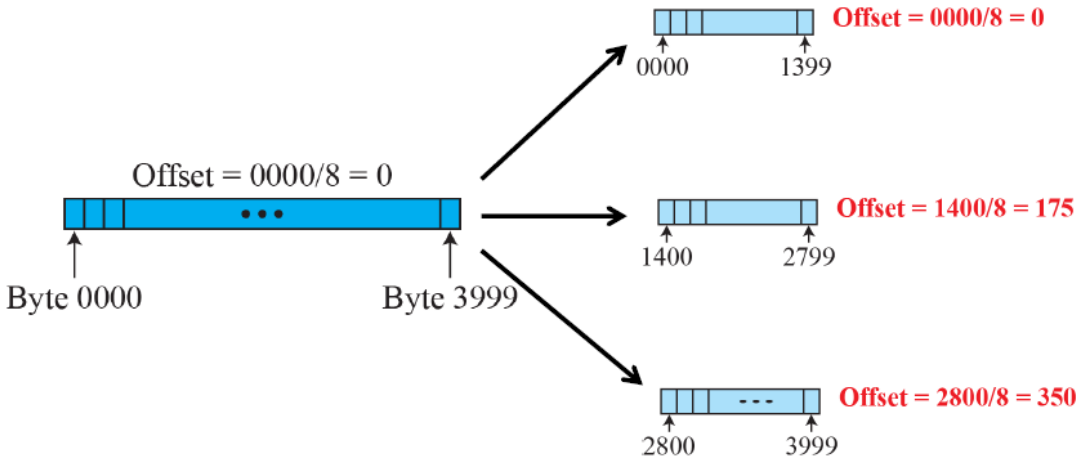
IP Packet Header



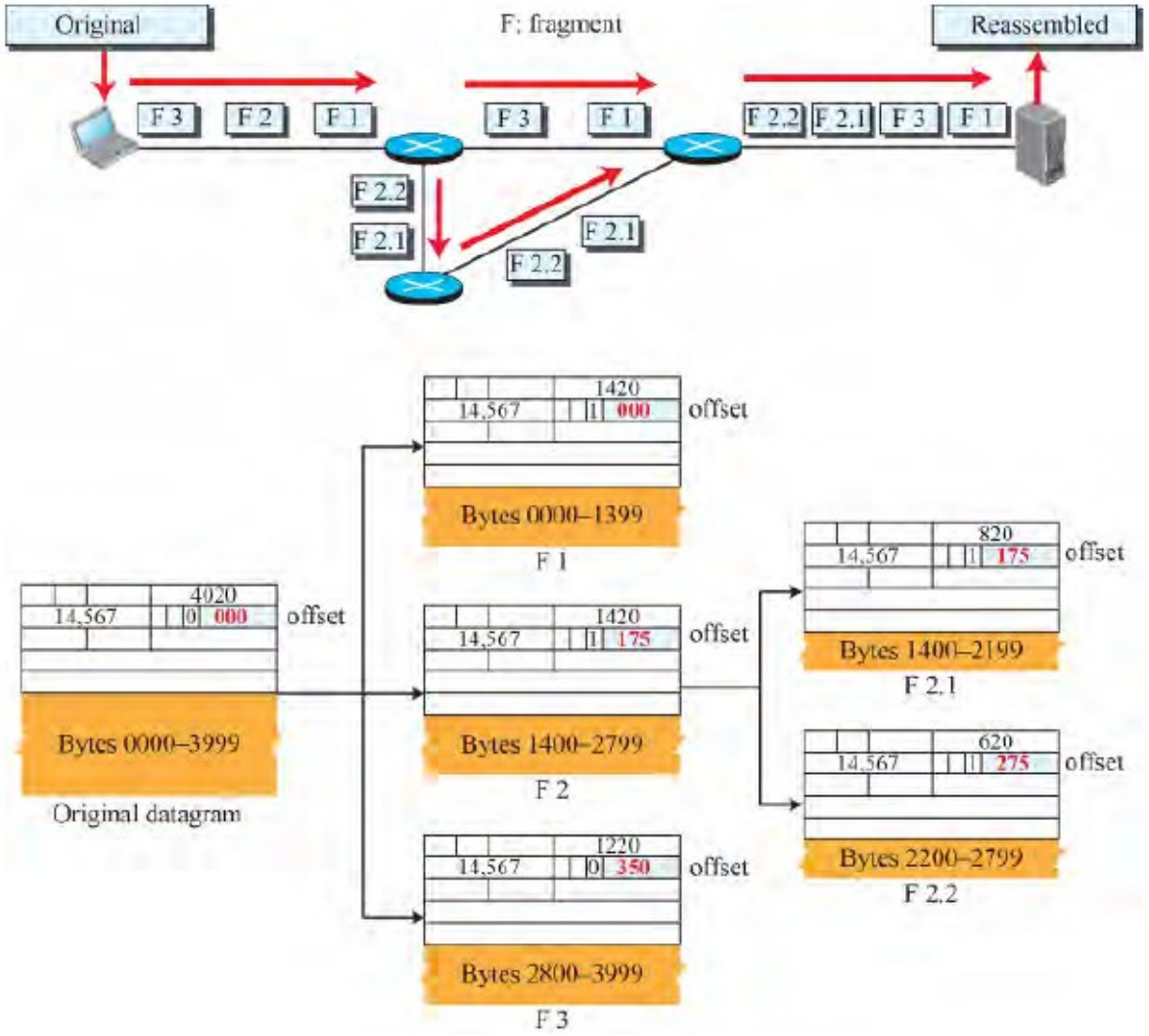
Option	Description
Security	Specifies how secret the datagram is
Strict source routing	Gives the complete path to be followed
Loose source routing	Gives a list of routers not to be missed
Record route	Makes each router append its IP address
Timestamp	Makes each router append its address and timestamp

IP Fragmentation & Reassembly

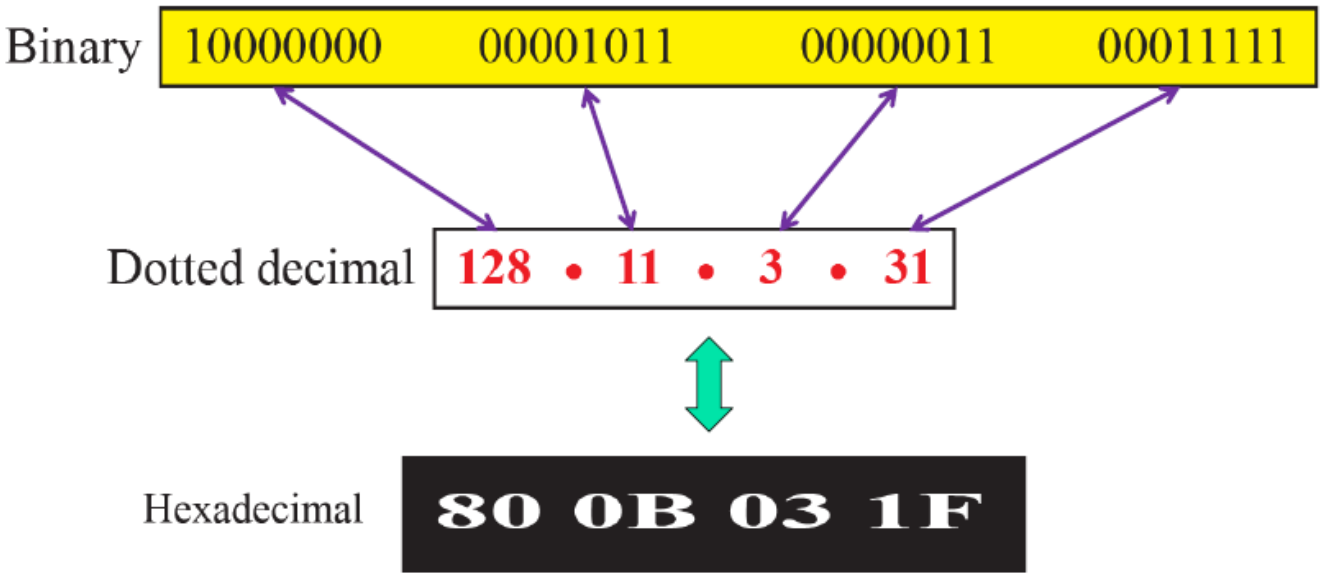




Fragmentation in detail



IP Address Classes



Address Hierarchy