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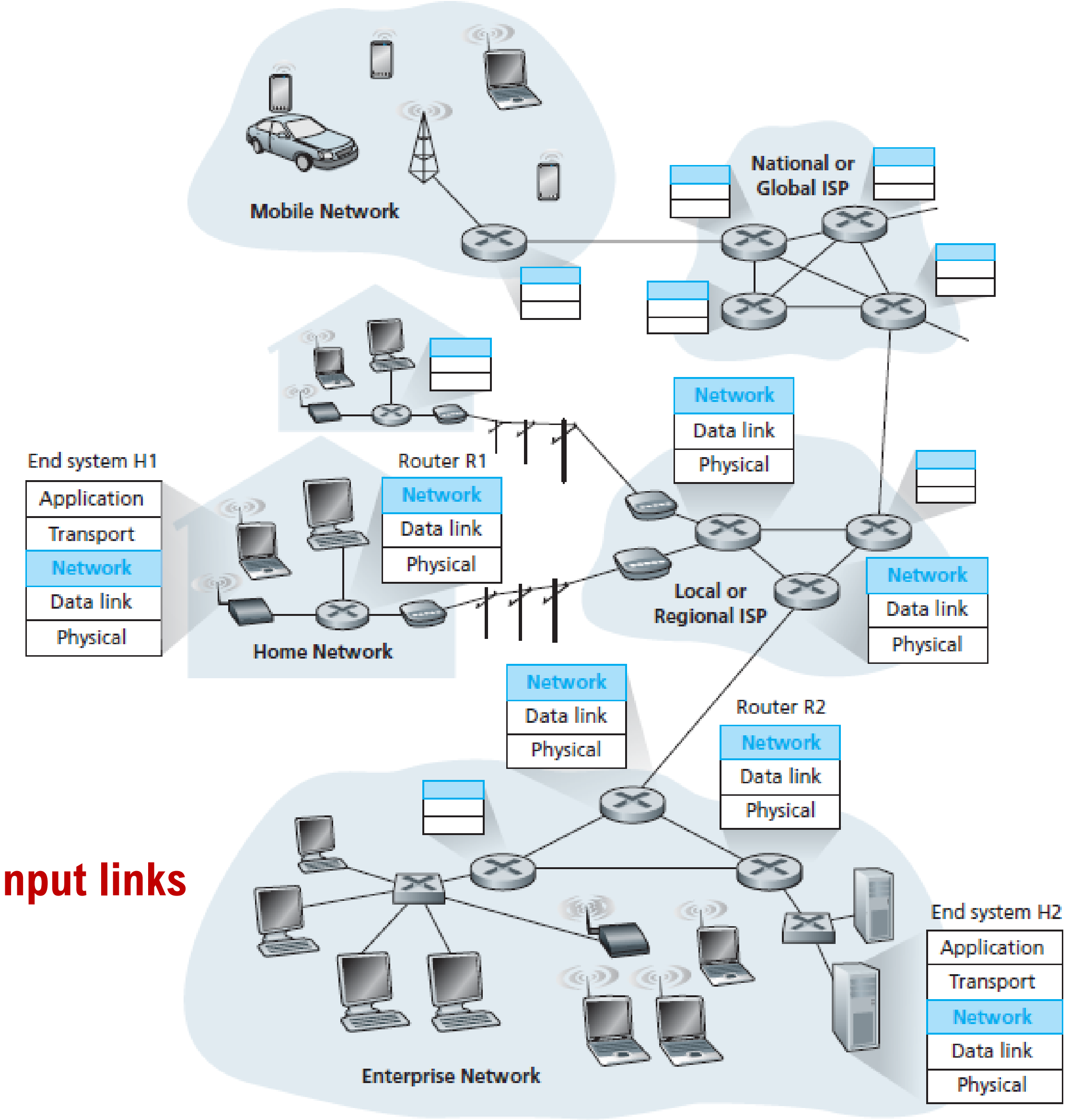
15CSE312
COMPUTER NETWORKS
3-0-0 3

Chapter 4: Network Layer

Network Layer

The network layer in H1 takes segments from the transport layer in H1, encapsulates each segment into a datagram (that is, a network-layer packet), and then sends the datagrams to its nearby router, R1. At the receiving host, H2, the network layer receives the datagrams from its nearby router R2, extracts the transport-layer segments, and delivers the segments up to the transport layer at H2.



The primary role of the routers is to forward datagrams from input links to output links

Fig shows a simple network with two hosts, H1 and H2, and several routers on the path between H1 and H2

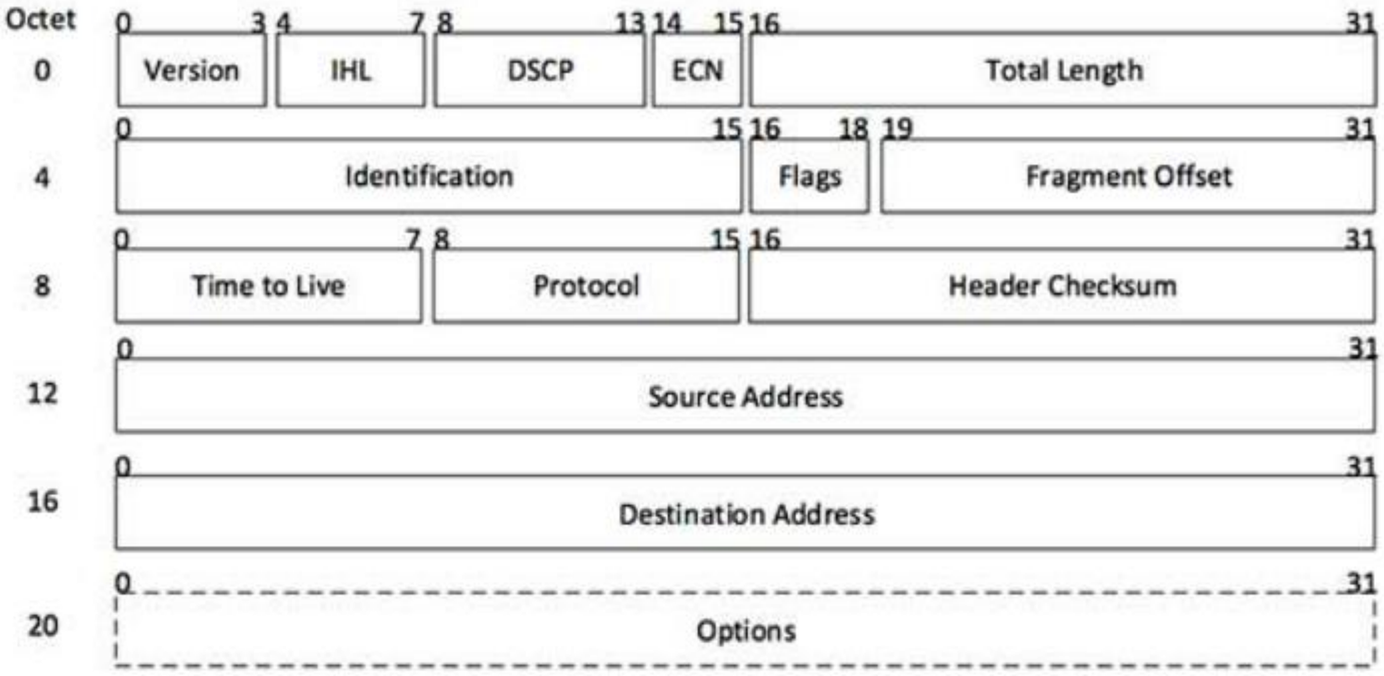
Network Layer- Functionality

- How a machine in a different network can communicate with a machine in another network
  - **Host to Host Delivery** (Source to Destination) using IP addressing
  - **Routing:** which is moving packets (the fundamental unit of data transport on modern computer networks) across the network using the most appropriate paths
  - **Fragmentation** : is done by the network layer when the maximum size of datagram is greater than maximum size of data that can be held in a frame i.e., its Maximum Transmission Unit (MTU). The network layer divides the datagram received from transport layer into fragments so that data flow is not disrupted.

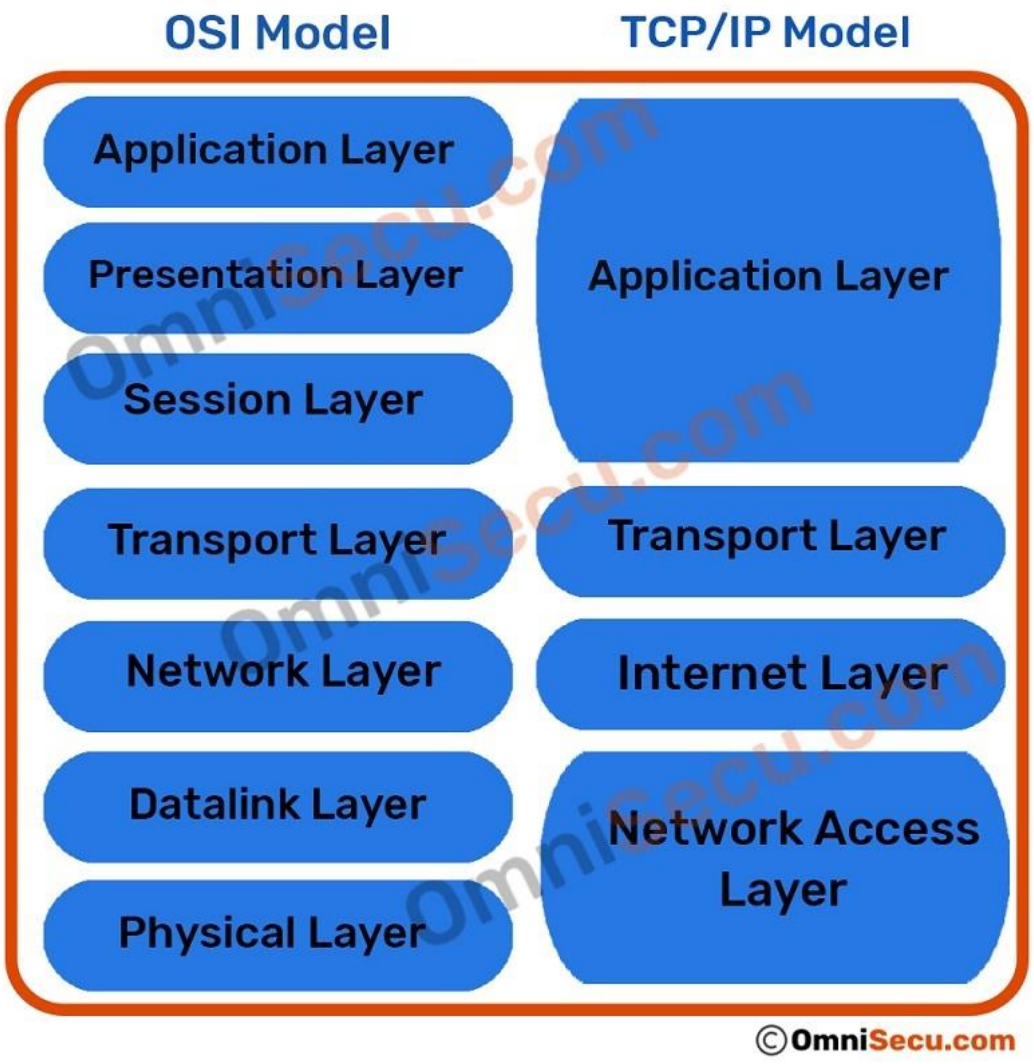
- The network layer is responsible for carrying data from one host to another.
- It provides means to allocate logical addresses to hosts, and identify them uniquely using the same.
- Network layer takes data units from Transport Layer and cuts them in to smaller unit called Data Packet.
- Network layer defines the data path, the packets should follow to reach the destination. Routers work on this layer and provides mechanism to route data to its destination.

IP packet encapsulates data unit received from above layer and add to its own header information.

(IP Encapsulation)



[Image: IP Header]



Internet Protocol version 4 (IPv4)

- Internet Protocol version 4 (IPv4) is the fourth version in the development of the Internet Protocol (IP) and the first version of the protocol to be widely deployed. IPv4 is described in IETF publication RFC 791 (September 1981)

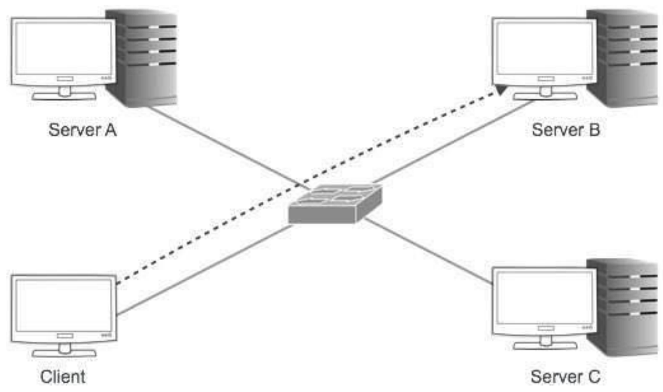
Communication between hosts can happen only if they can identify each other on the network. In a single collision domain (where every packet sent on the segment by one host is heard by every other host) hosts can communicate directly via MAC address. MAC address is a factory coded 48-bits hardware address which can also uniquely identify a host. But if a host wants to communicate with a remote host, i.e. not in the same segment or logically not connected, then some means of addressing is required to identify the remote host uniquely. A logical address is given to all hosts connected to Internet and this logical address is called **Internet Protocol Address**.

IPv6 is the next generation Internet Protocol (IP) standard intended to eventually replace IPv4, the protocol many Internet services still use today.

IPv4 supports three different types of addressing modes. −

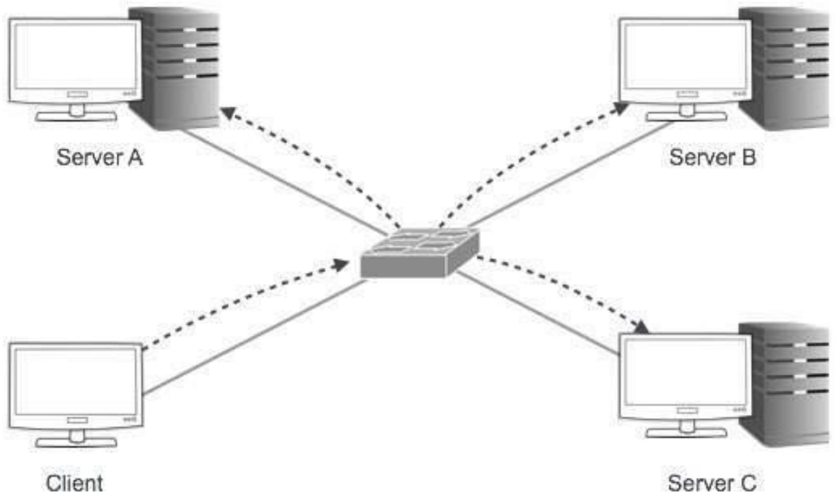
Unicast Addressing Mode

In this mode, data is sent only to one destined host. The Destination Address field contains 32- bit IP address of the destination host. Here the client sends data to the targeted server



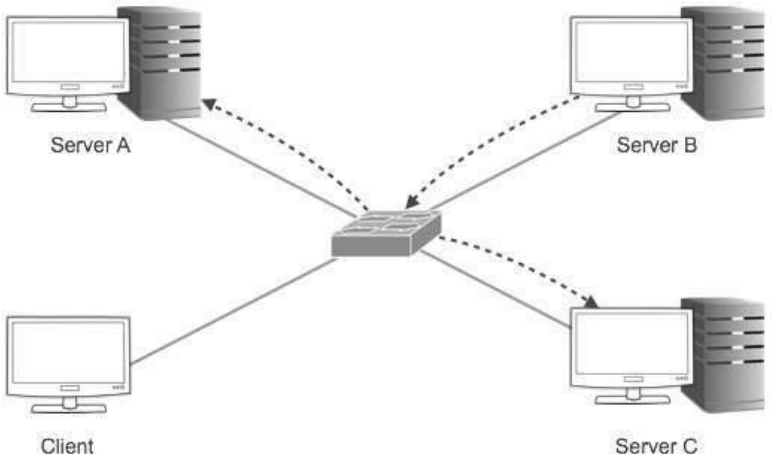
Broadcast Addressing Mode

In this mode, the packet is addressed to all the hosts in a network segment. The Destination Address field contains a special broadcast address, i.e. **255.255.255.255**. When a host sees this packet on the network, it is bound to process it. Here the client sends a packet, which is entertained by all the Servers −



Multicast Addressing Mode

This mode is a mix of the previous two modes, i.e. the packet sent is neither destined to a single host nor all the hosts on the segment. In this packet, the Destination Address contains a special address which starts with 224.x.x.x and can be entertained by more than one host.



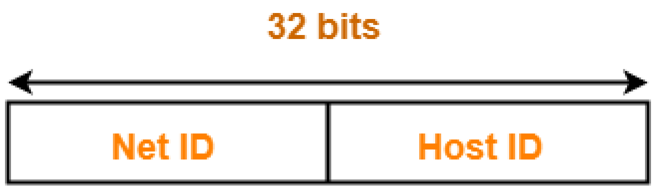
IP Address in Networking-

Internet Corporation for Assigned Names and Numbers is responsible for assigning IP addresses.

An **IP address** consists of two components: a **network ID** and a **host ID**.

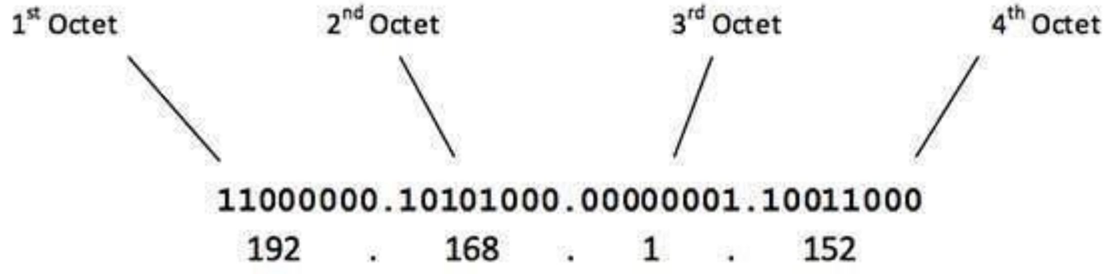
- The **network ID** identifies the **network** segment to which the **host** belongs. The **host ID** identifies an individual **host** on some specific **network** segment. A **host** can communicate directly only with other **hosts** on the same **network** segment.

•IP Address is short for **Internet Protocol Address**.
•It is a unique address assigned to each computing device in an IP network.
•ISP assigns IP Address to all the devices present on its network.
•Computing devices use IP Address to identify and communicate with other devices in the IP network.



Format of an IP Address

•IP Address is a 32 bit binary address written as 4 numbers separated by dots.
•The 4 numbers are called as **octets** where each octet has 8 bits.
•The octets are divided into 2 components- Net ID and Host ID.



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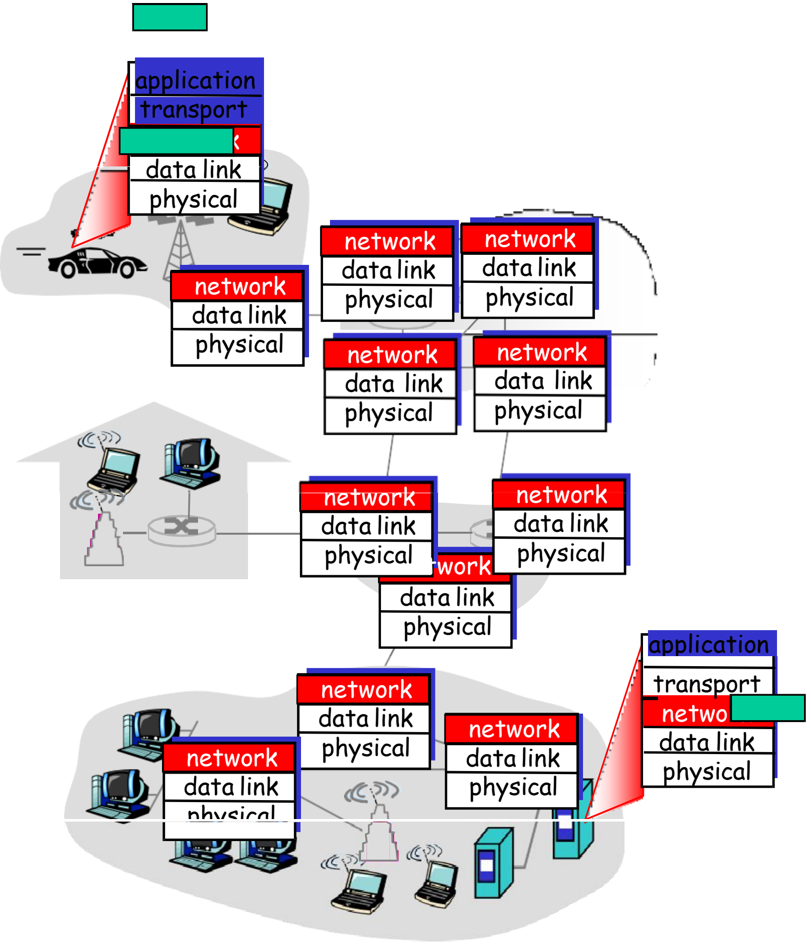
- 4. 1 Introduction
- 4.2 Virtual circuit and datagram networks
- 4.3 What's inside a router
- 4.4 IP: Internet Protocol
  - Datagram format
  - IPv4 addressing
  - ICMP
  - IPv6
- 4.5 Routing algorithms
  - Link state
  - Distance Vector
  - Hierarchical routing
- 4.6 Routing in the Internet
  - RIP
  - OSPF
  - BGP
- 4.7 Broadcast and multicast routing

Network layer

- transport segment from sending to receiving host
- on sending side encapsulates segments into datagrams
- on rcving side, delivers segments to transport layer
- network layer protocols in *every* host, router
- router examines header fields in all IP datagrams passing through it



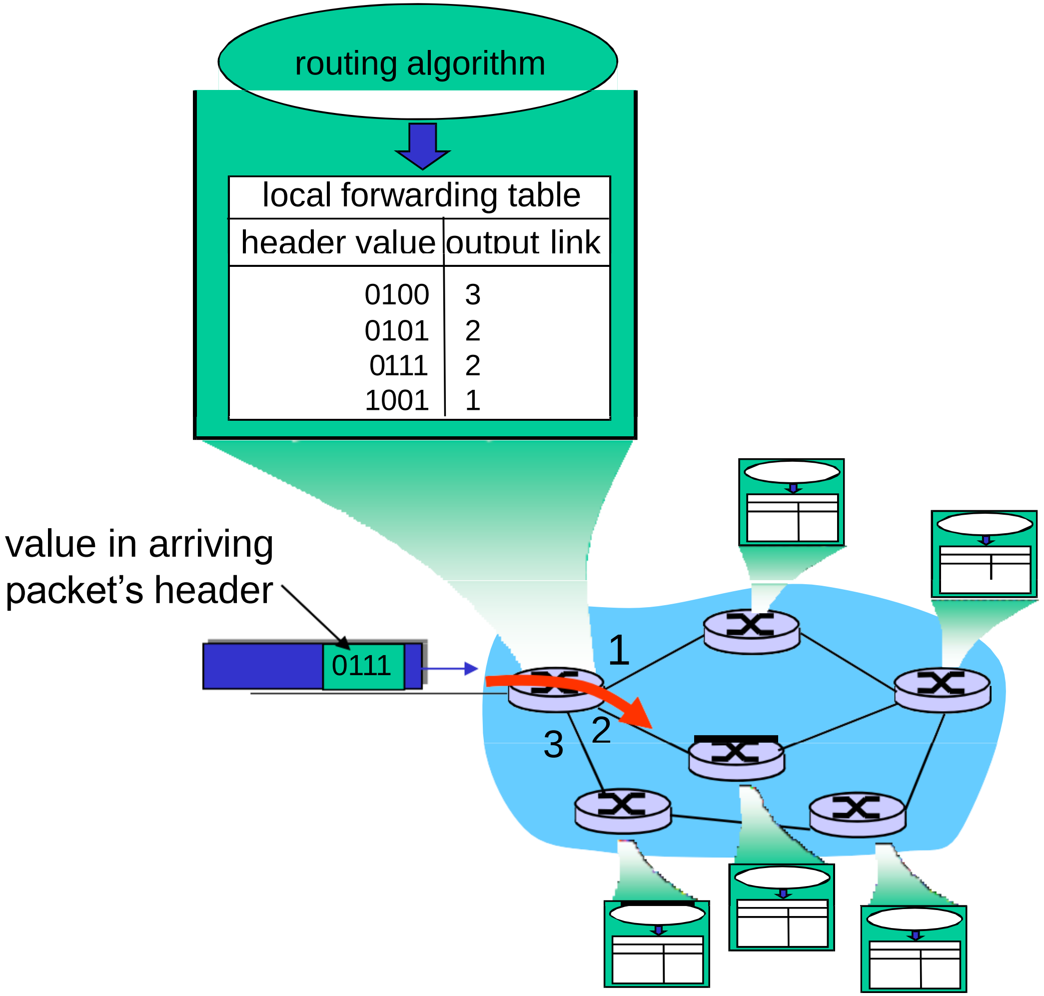
Two Key Network-Layer Functions

- *forwarding* move packets from router's input to appropriate router output
- *routing:* determine route taken by packets from source to dest.
  - *routing algorithms*

analogy:

- routing: process of planning trip from source to dest
- forwarding: process of getting through single interchange

Interplay between routing and forwarding



Connection setup

- 3rd important function in *some* network architectures:
  - ATM, frame relay, X.25
- before datagrams flow, two end hosts *and* intervening routers establish virtual connection
  - routers get involved
- network vs transport layer connection service:
  - network: between two hosts (may also involve intervening routers in case of VCs)
  - transport: between two processes

Network service model

Q: What *service model* for "channel" transporting datagrams from sender to receiver?

Example services for individual datagrams:

- guaranteed delivery
- guaranteed delivery with less than 40 msec delay

Example services for a flow of datagrams:

- in-order datagram delivery
- guaranteed minimum bandwidth to flow
- restrictions on changes in inter-packet spacing

Network layer service models:

Network Architecture	Service Model	Guarantees ? Bandwidth	Loss	Order	Timing	Congestion feedback
Internet	best effort	none	no	no	no	no (inferred via loss)
ATM	CBR	constant rate	yes	yes	yes	no congestion
ATM	VBR	guaranteed rate	yes	yes	yes	no congestion
ATM	ABR	guaranteed minimum	no	yes	no	yes
ATM	UBR	none	no	yes	no	no

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Network layer connection and connection-less service

- datagram network provides network-layer connectionless service
- VC network provides network-layer connection service
- analogous to the transport-layer services, but:
  - service: host-to-host
  - no choice: network provides one or the other
  - implementation: in network core

Virtual circuits

"source-to-dest path behaves much like telephone circuit"

- performance-wise
- network actions along source-to-dest path

- call setup, teardown for each call *before* data can flow
- each packet carries VC identifier (not destination host address)
- *every* router on source-dest path maintains "state" for each passing connection
- link, router resources (bandwidth, buffers) may be *allocated* to VC (dedicated resources = predictable service)

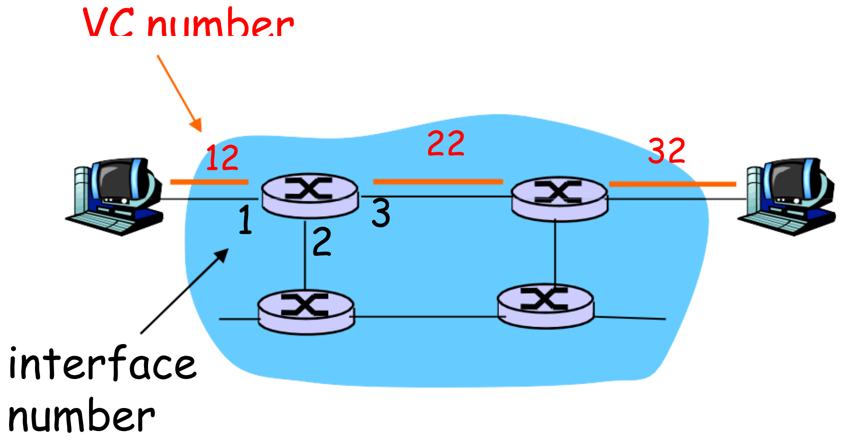
VC implementation

a VC consists of:

1. path from source to destination
2. VC numbers, one number for each link along path
3. entries in forwarding tables in routers along path

- packet belonging to VC carries VC number (rather than dest address)
- VC number can be changed on each link.
  - New VC number comes from forwarding table

Forwarding table



Forwarding table in northwest router:

Incoming interface	Incoming VC #	Outgoing interface	Outgoing VC #
1	12	3	22
2	63	1	18
3	7	2	17
1	97	3	87
…	…	…	…

Routers maintain connection state information!

Datagram or VC network: why?

Internet (datagram)

- data exchange among computers
  - "elastic" service, no strict timing req.
- "smart" end systems (computers)
  - can adapt, perform control, error recovery
  - simple inside network, complexity at "edge"
- many link types
  - different characteristics
  - uniform service difficult

ATM (VC)

- evolved from telephony
- human conversation:
  - strict timing, reliability requirements
  - need for guaranteed service
- "dumb" end systems
  - telephones
  - complexity inside network

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Router Architecture Overview

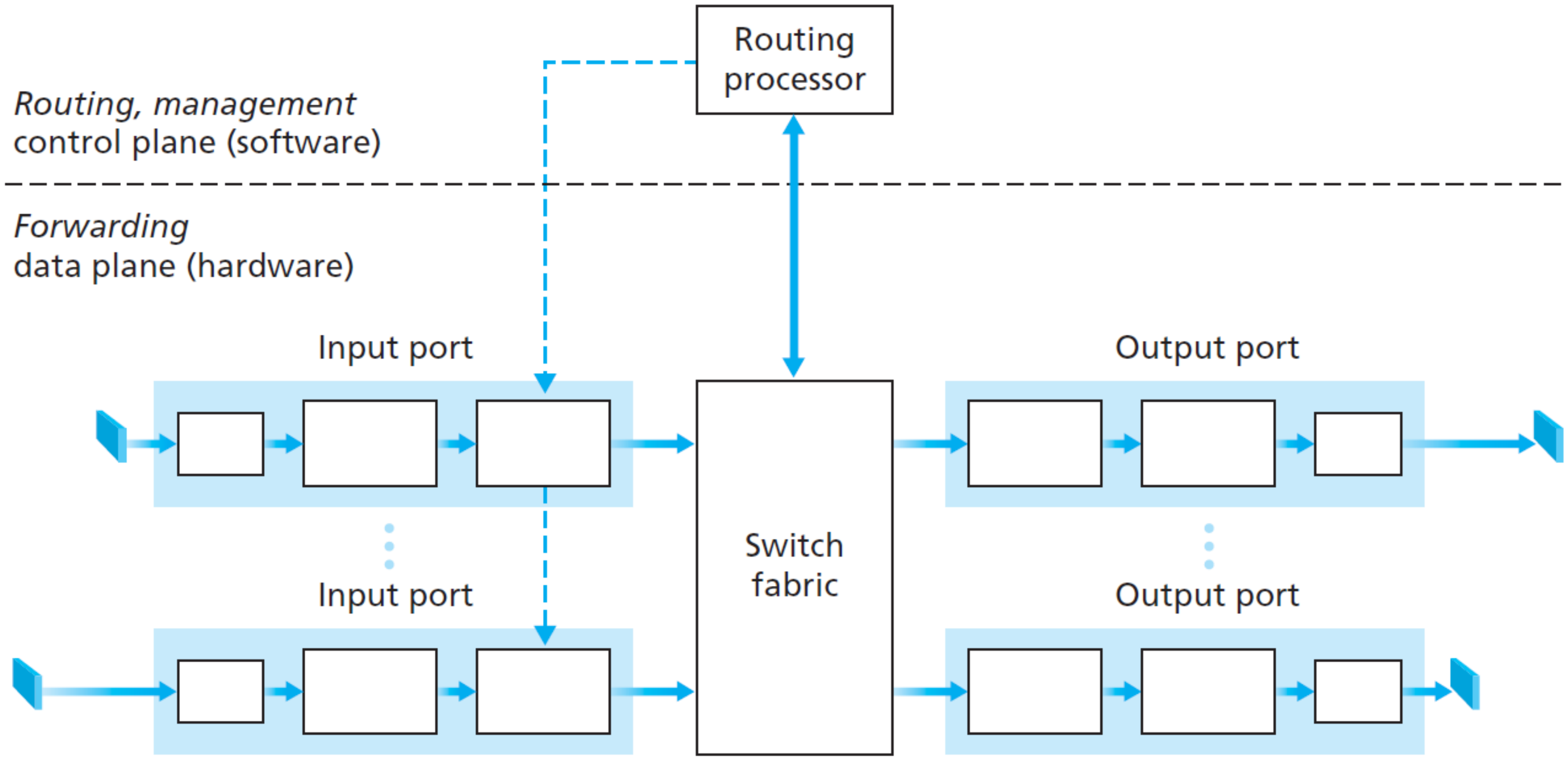


Figure 4.6 ♦ Router architecture

Router Architecture Overview

Input Port : It performs the physical layer function of terminating an incoming physical link at a router

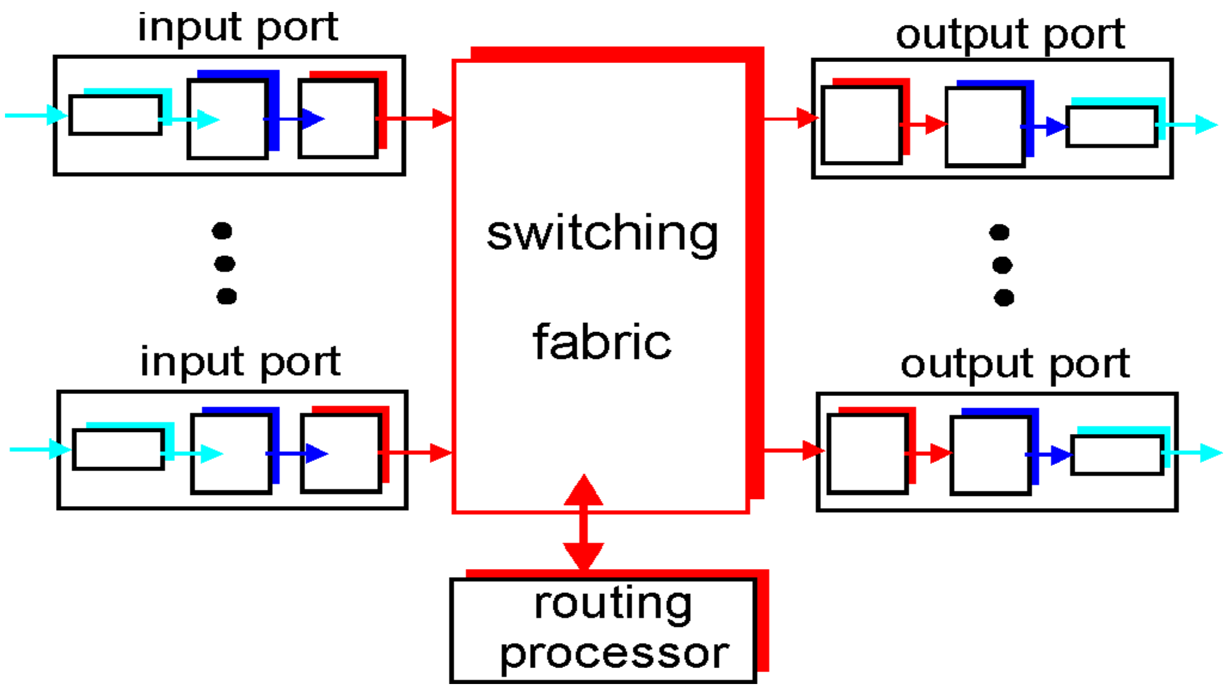
Two key router functions:

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

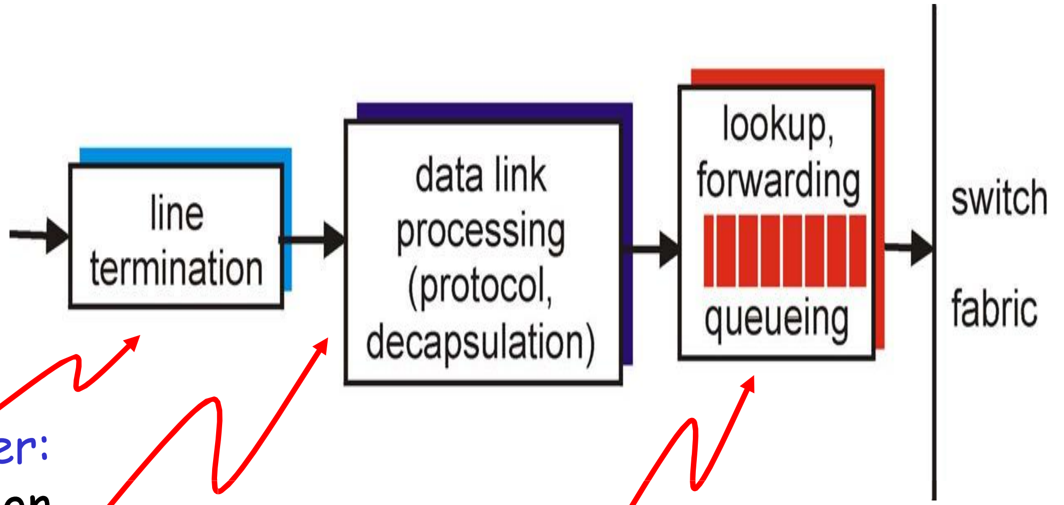
Switching fabric. The switching fabric connects the router's input ports to its output ports. This switching fabric is completely contained within the router— a network inside of a network router!

Routing processor. The routing processor executes the routing protocols

Output ports. An output port stores packets received from the switching fabric and transmits these packets on the outgoing link by performing the necessary link-layer and physical-layer functions



Input Port Functions



Physical layer:
bit-level reception

Data link layer:
e.g., Ethernet
see chapter 5

Decentralized switching:

- given datagram dest., lookup output port using forwarding table in input port memory
- goal: complete input port processing at 'line speed'
- queuing: if datagrams arrive faster than forwarding rate into switch fabric

Three types of switching fabrics

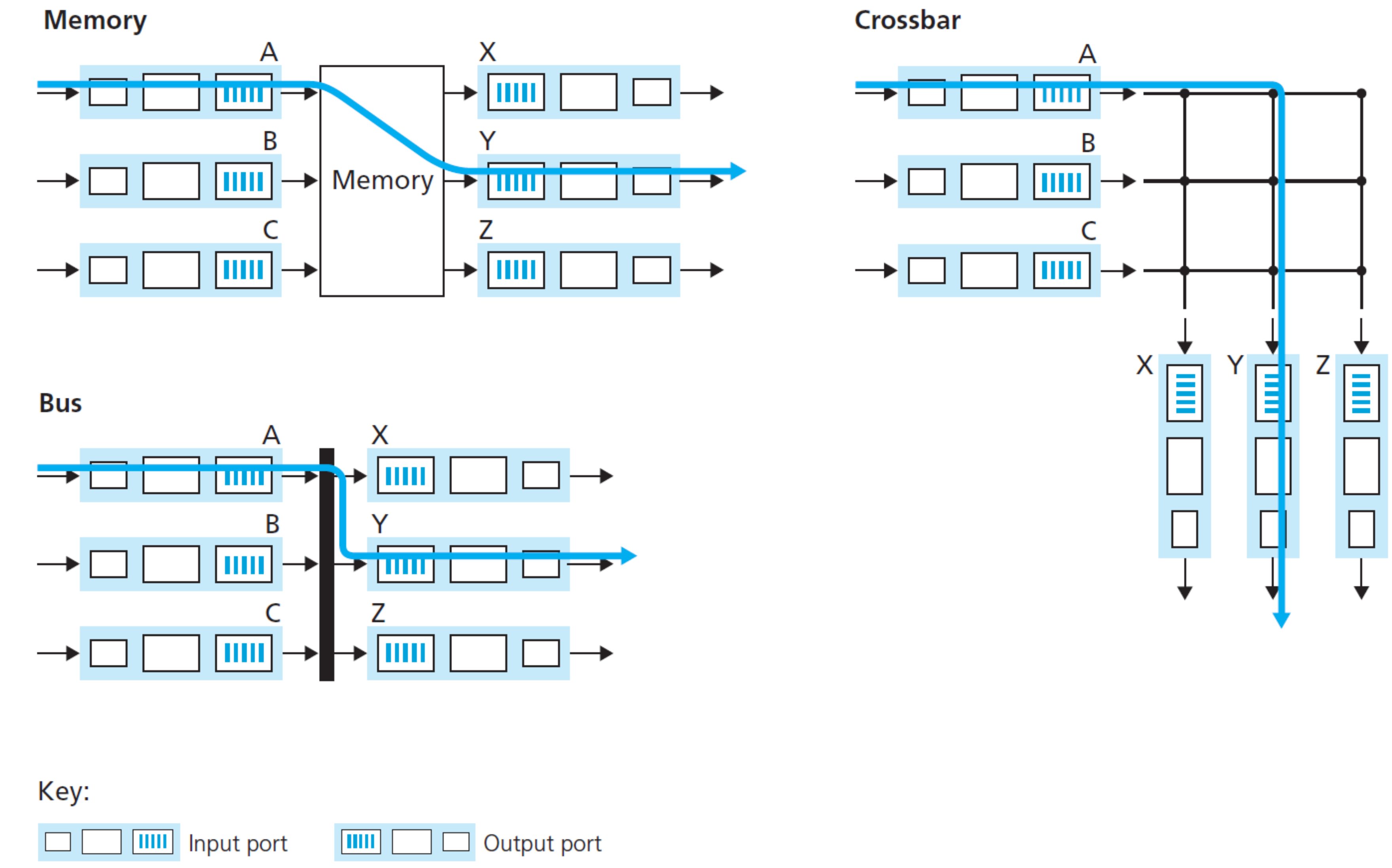
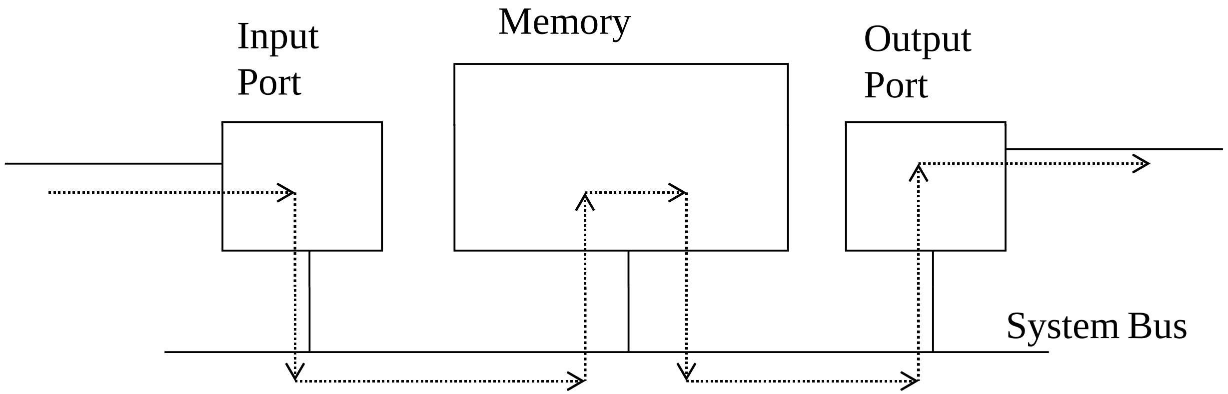


Figure 4.8 ♦ Three switching techniques

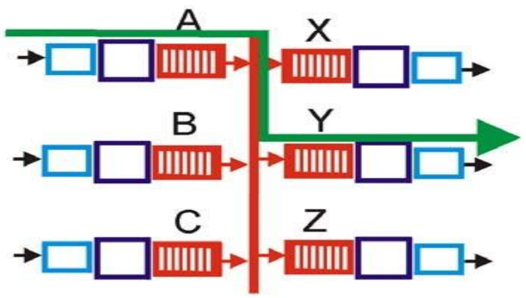
Switching Via Memory

First generation routers:

- traditional computers with switching under direct control of CPU
- packet copied to system's memory
- speed limited by memory bandwidth



Switching Via a Bus

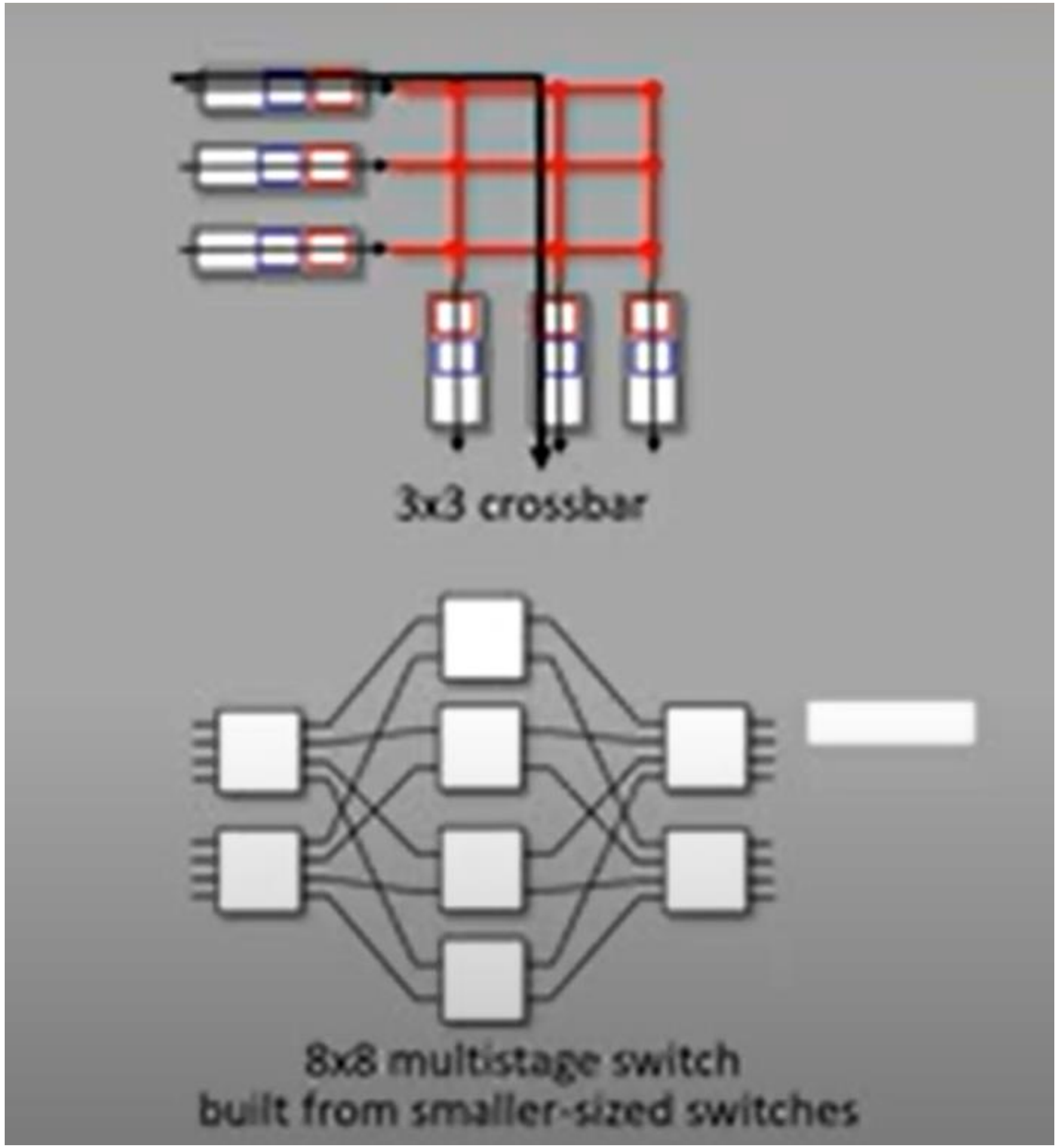


- datagram from input port memory to output port memory via a shared bus
- bus contention: switching speed limited by bus bandwidth
- 32 Gbps bus, Cisco 5600: sufficient speed for access and enterprise routers

Switching Via An Interconnection

Network

- overcome bus bandwidth limitations
- Banyan networks, other interconnection nets initially developed to connect processors in multiprocessor
- advanced design: fragmenting datagram into fixed length cells, switch cells through the fabric.
- Cisco 12000: switches 60 Gbps through the interconnection network



Input Port Queuing

- Fabric slower than input ports combined -> queueing may occur at input queues
- Head-of-the-Line (HOL) blocking: queued datagram at front of queue prevents others in queue from moving forward
- *queueing delay*
- *and loss due to input buffer overflow!*

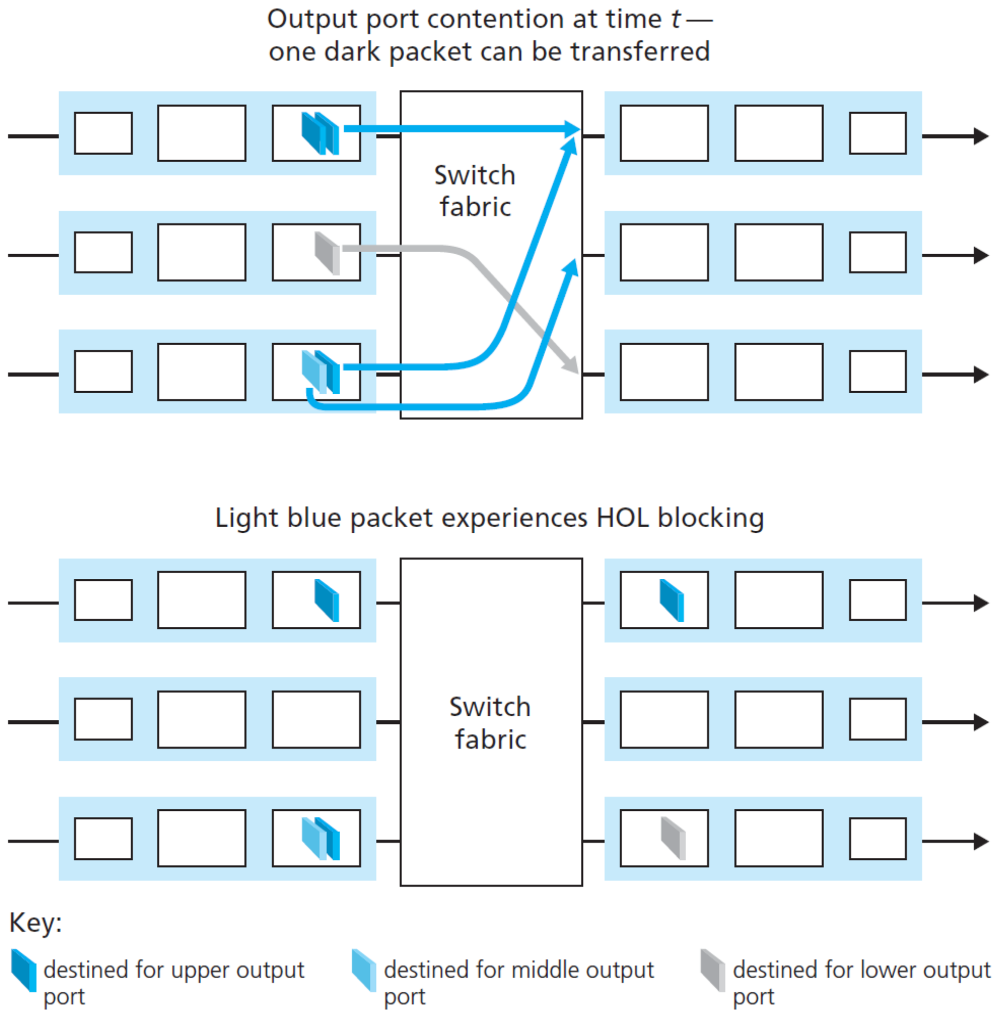
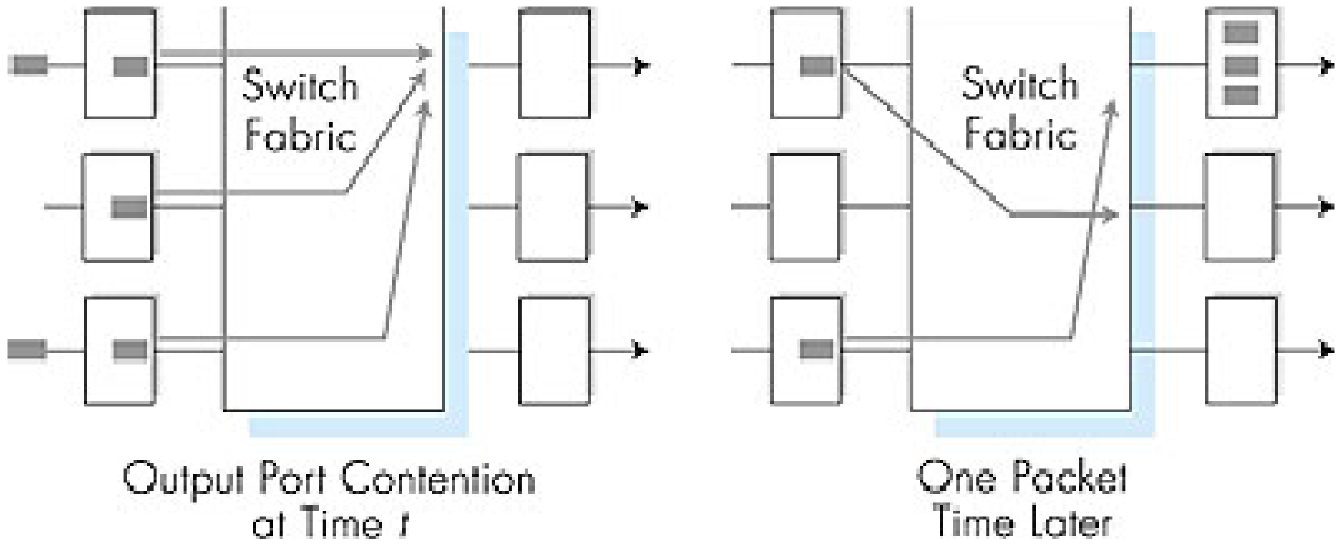


Figure 4.11 ♦ HOL blocking at an input queued switch

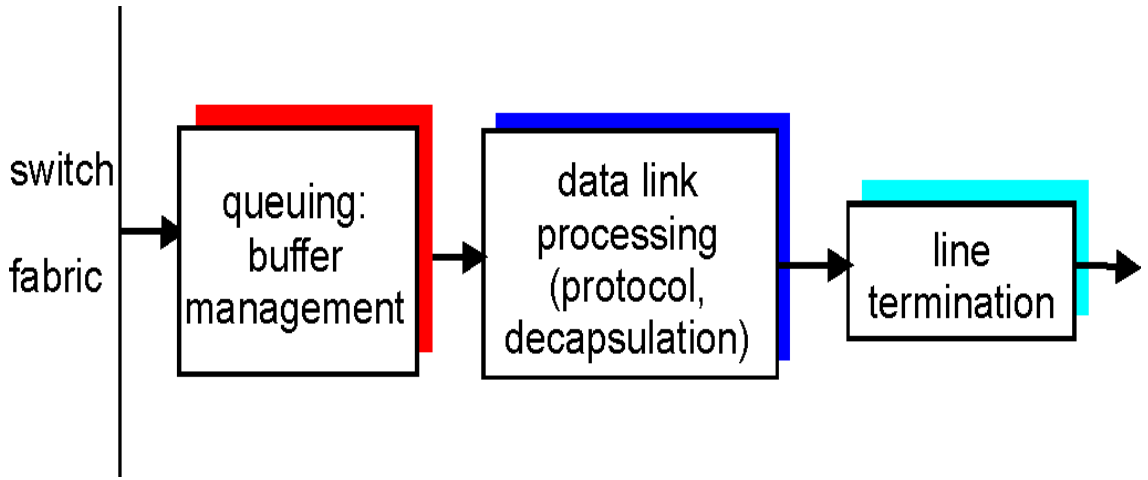
Output port queueing



- buffering when arrival rate via switch exceeds output line speed
- *queueing (delay) and loss due to output port buffer overflow*

Output Ports

- A consequence of output port queuing is that a packet scheduler at the output port must choose one packet among those queued for transmission.
- This selection might be done on a simple basis, such as
  - first-come-first-served (FCFS) scheduling,
  - Roundrobin scheduling
  - weighted fair queuing (WFQ),
    - which shares the outgoing link fairly among the different end-to-end connections that have packets queued for transmission.



- *Buffering* required when datagrams arrive from fabric faster than the transmission rate
- *Scheduling discipline* chooses among queued datagrams for transmission

How much buffering?

- RFC 3439 rule of thumb: average buffering equal to "typical" RTT (say 250 msec) times link capacity C
  - e.g., C = 10 Gps link: 2.5 Gbit buffer
- Recent recommendation: with N flows, buffering equal to $\dfrac{RTT \cdot C}{\sqrt{N}}$

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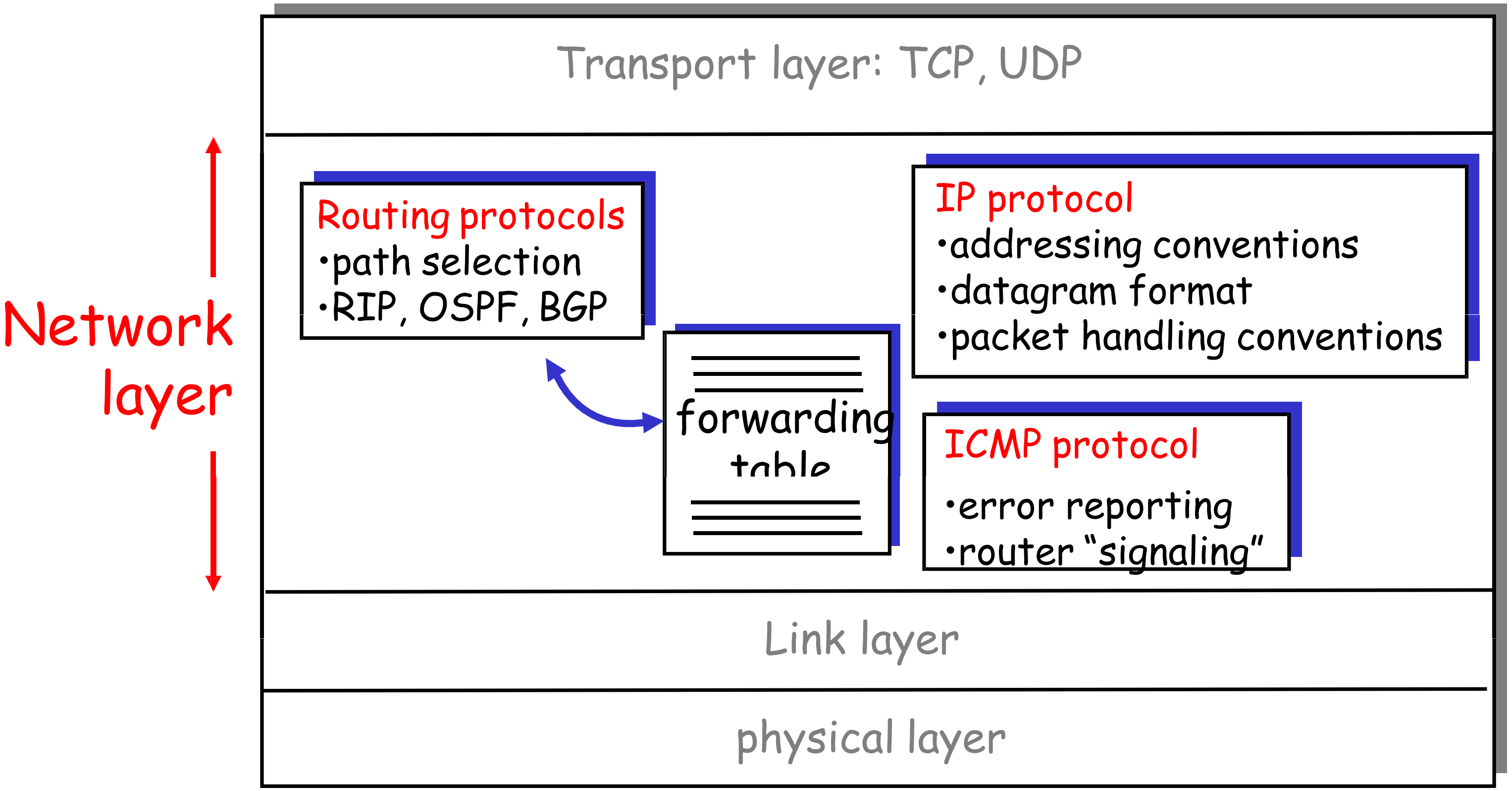
The Internet Network layer

Host, router network layer functions:



Namah Shivaya