

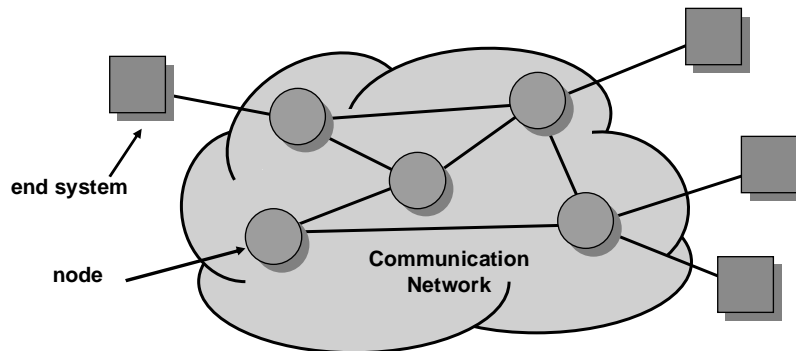
# Switching Networks

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# Communication Networks

- A generic communication network:



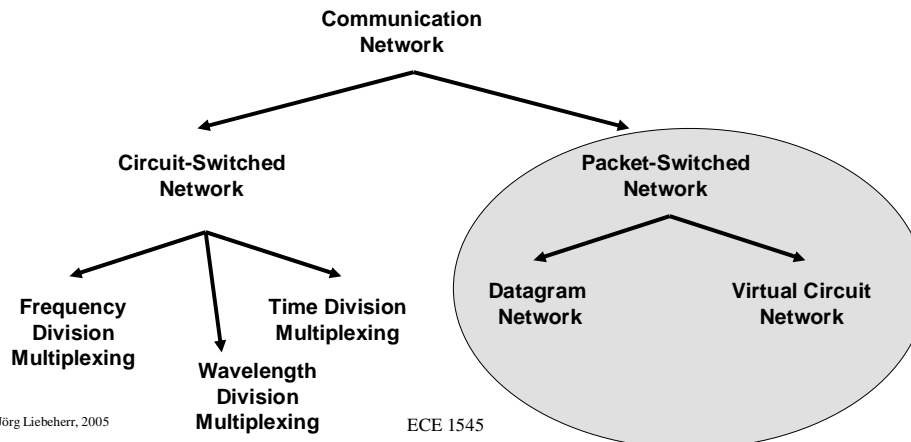
Other names for "end system": station, **host**, terminal  
Other names for "node": switch, **router**, gateway

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## Taxonomy of Networks

- Communication networks can be classified based on the way in which the nodes exchange information:



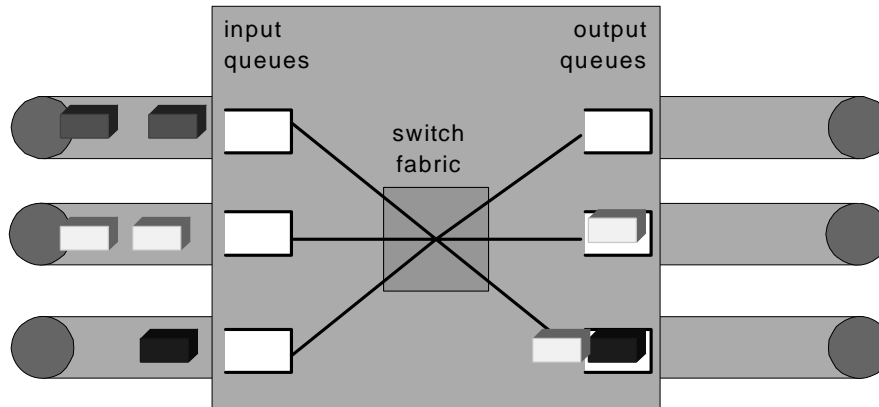
## Packet Switching

- Data are sent as formatted bit-sequences, so-called packets
- Packets have the following structure:



- Header and Trailer carry control information
- Each packet is passed through the network from node to node along some path (**Forwarding/Routing**)
- At each node the entire packet is received, stored briefly, and then forwarded to the next node (**Store-and-Forward Networks**)
- Packet transmission is never interrupted (no preemption)
- No capacity is allocated for packets

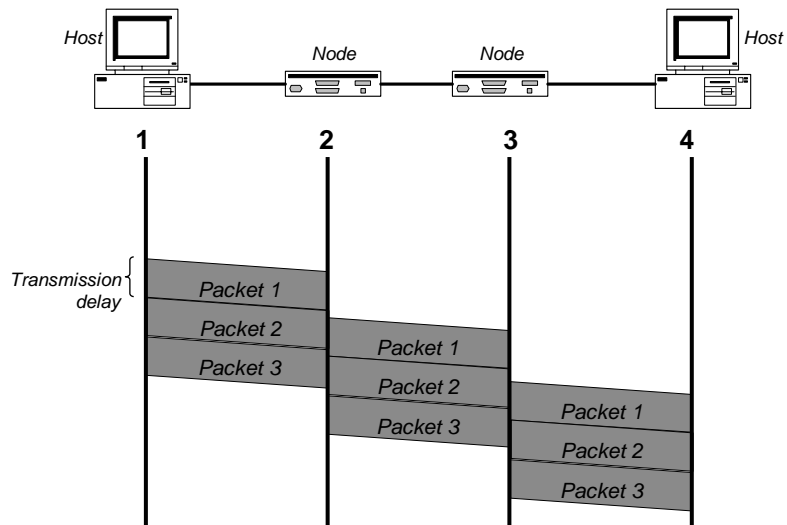
## A Packet Switch



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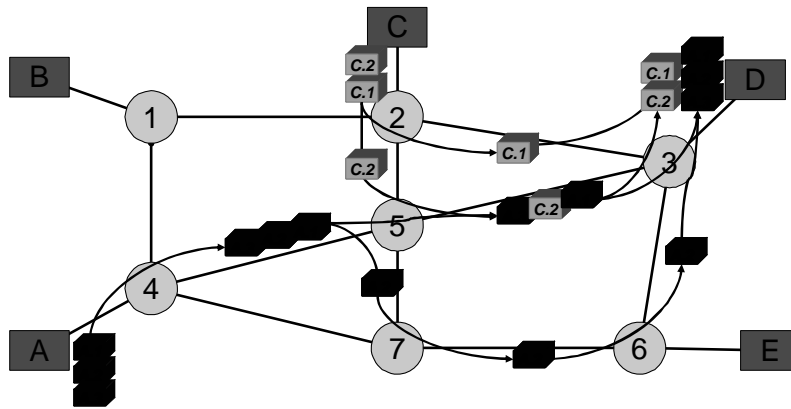
## Timing of Datagram Packet Switching



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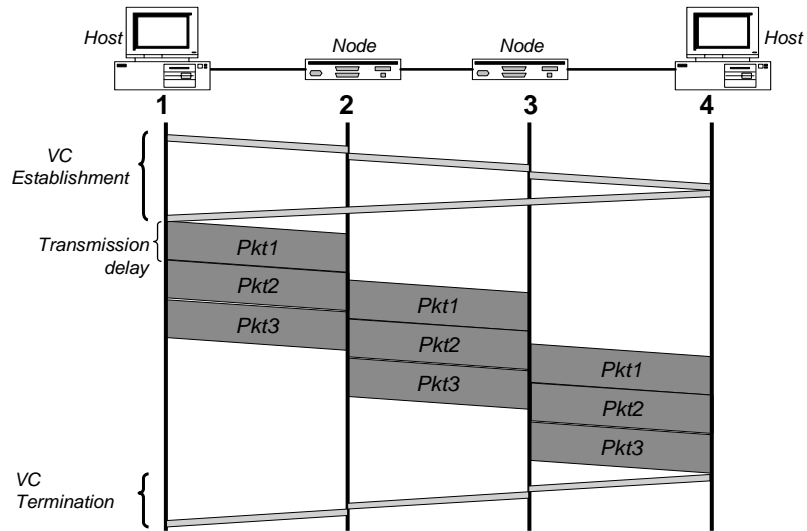
## Datagram Packet Switching



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## Timing of VC Packet Switching



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## Packet Switch Architectures

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## Packet Switches

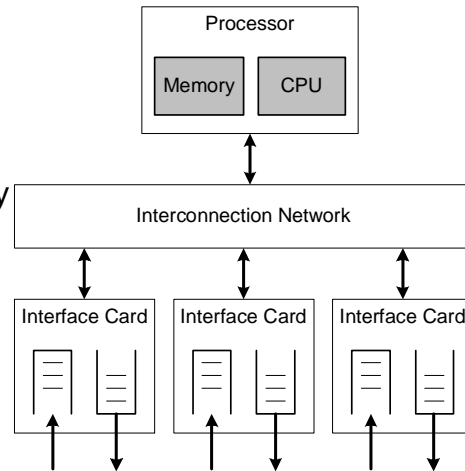
- Different types of packet switches:
  - IP routers
  - ATM switches
  - MPLS switches
  - Ethernet (LAN) switches
  - Frame Relay
- All types of packet switches have very similar characteristics

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## Switch Components

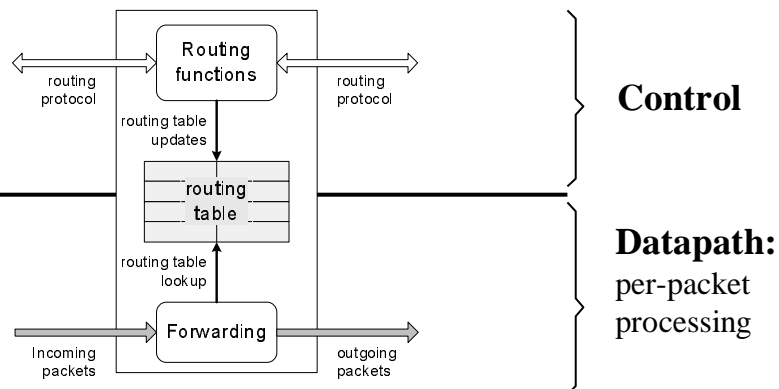
- Hardware components of a router:
  - Network interfaces
  - Interconnection network
  - Processor with a memory and CPU



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## Functional Components



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## Routing and Forwarding

Routing functions include:

- route calculation
- maintenance of the routing table
- execution of routing protocols

Forwarding is per-packet processing

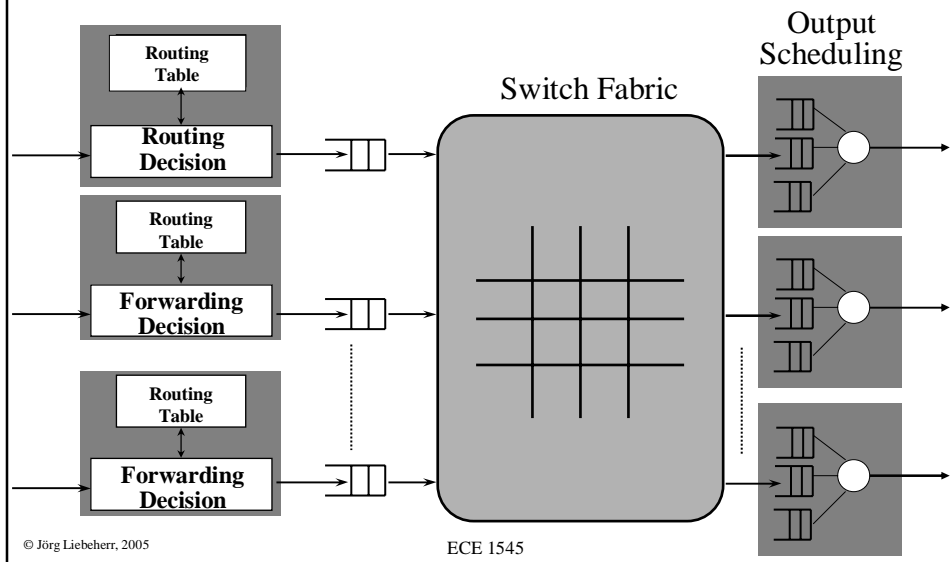
- On high-end packet switches routers, forwarding is highly parallelized, and most work is done on the interface cards

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## Basic Architectural Components

*Per-packet processing*



## IP Router

- Lookup packet destination address in forwarding table.
  - If known, forward to correct port.
  - If unknown, drop packet.
- Decrement TTL, update header checksum.
- Forward packet to outgoing interface.
- Transmit packet onto link.

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## ATM Switch

- Look up VCI/VPI of cell in VC table.
- Replace old VCI/VPI with new.
- Forward cell to outgoing interface.
- Transmit cell onto link.

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## Ethernet Switch

- Lookup frame destination address in forwarding table.
  - If known, forward to correct port.
  - If unknown, broadcast to all ports.
- Learn source address of incoming frame.
- Forward frame to outgoing interface.
- Transmit frame onto link.

## Forwarding in IP Networks

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## Internet technology

- Internet is based on **datagram packet-switching** technology
- Packet switches are called **IP routers**.
- The protocol that forwards packets in the Internet is the Internet Protocol or IP.
- Packets are called **IP datagrams**. Each datagram has a **source IP address** and a **destination IP address**

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## Network number and Host number

- An IPv4 address has two parts:
  - A network prefix identifies an IP network
  - A host number identifies an interface on that network

network prefix      host number

- **How long is the network prefix?**
  - The length of the network prefix must be indicatedPrefix notation:      128.143.137.144/16  
Netmask:              128.143.137.144 255.255.0.0

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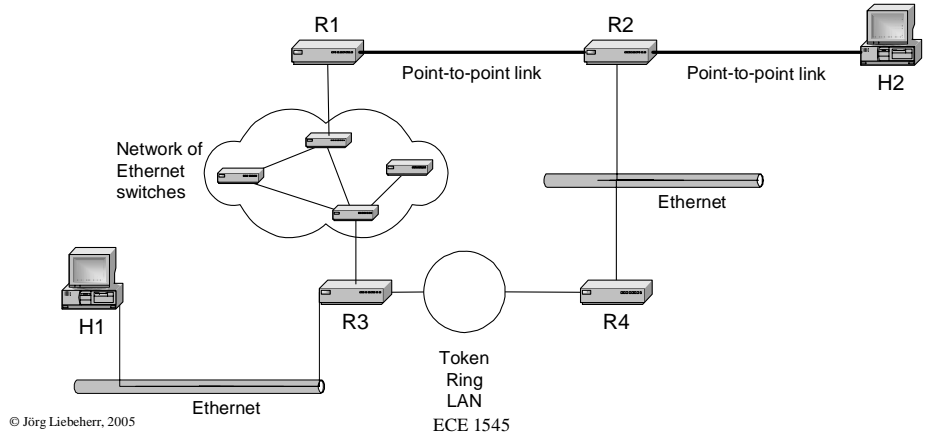
## IP Forwarding

- The term “Internet” refers to an internetwork of IP networks
- An IP network is a logical entity that is defined by a network prefix
  - The IP address of an IP network is a network prefix with the host number set to zero
  - Example 128.143.0.0/16
- In the Internet, IP provides an end-to-end delivery service for IP datagrams between hosts:
  - The delivery service is realized with the help of IP routers
  - Routers use the IP destination address in an IP datagram to find a network:
    - Step 1: Forward the datagram to the right IP network
    - Step 2: Forward the datagram to the right IP interface

**Note: The concepts of autonomous system and IP network are different.**  
Autonomous systems typically consists of many IP networks that belong to the same organization and are administered under the same authority

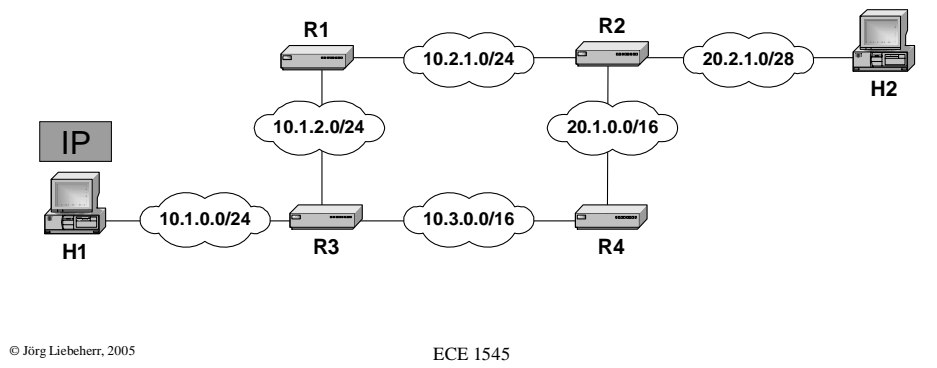
## Delivery of an IP datagram

- View at the data link layer layer:
  - Internetwork is a collection of LANs or point-to-point links or switched networks that are connected by routers



## Delivery of an IP datagram

- View at the IP layer:
  - An IP network is a logical entity with a network number
  - We represent an IP network as a “cloud”
  - The IP delivery service takes the view of clouds, and ignores the data link layer view



# Routing tables

- Each router and each host keeps a **routing table** which tells the router how to process an outgoing packet
- Main columns:
  1. **Destination address:** where is the IP datagram going to?
  2. **Next hop or interface:** how to send the IP datagram?
- Routing tables are set so that datagrams gets closer to the its destination

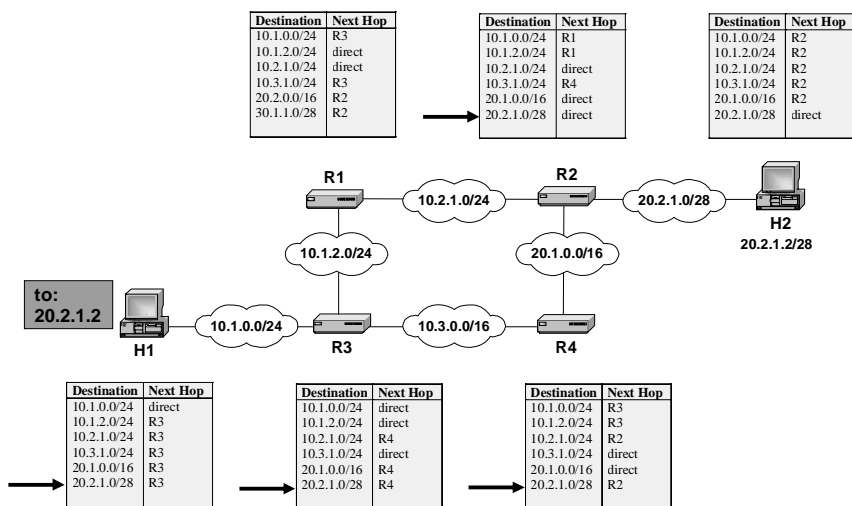
Routing table of a host or router  
 IP datagrams can be locally delivered ("direct") or sent to a router ("R4")

Destination	Next Hop
10.1.0.0/24	direct
10.1.2.0/24	direct
10.2.1.0/24	R4
10.3.1.0/24	direct
20.1.0.0/16	R4
20.2.1.0/28	R4

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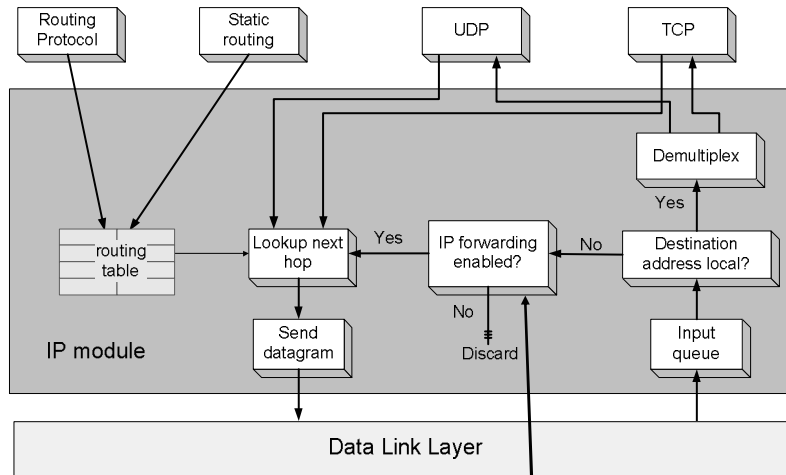
# Delivery with routing tables



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## Forwarding an IP datagram (host or router)



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IP router: IP forwarding enabled  
Host: IP forwarding disabled

## Longest Prefix Match

**Longest Prefix Match:** Search for the routing table entry that has the longest match with the prefix of the destination IP address

1. Search for a match on all 32 bits
2. Search for a match for 31 bits
- .....
32. Search for a match on 0 bits

Host route, loopback entry  
→ 32-bit prefix match  
Default route is represented as 0.0.0.0/0  
→ 0-bit prefix match

128.143.71.21

Destination address	Next hop
10.0.0.0/8	R1
128.143.0.0/16	R2
128.143.64.0/20	R3
128.143.192.0/20	R3
128.143.71.0/24	R4
128.143.71.55/32	R3
default	R5

**The longest prefix match for 128.143.71.21 is for 24 bits with entry 128.143.71.0/24**

**Datagram will be sent to R4**

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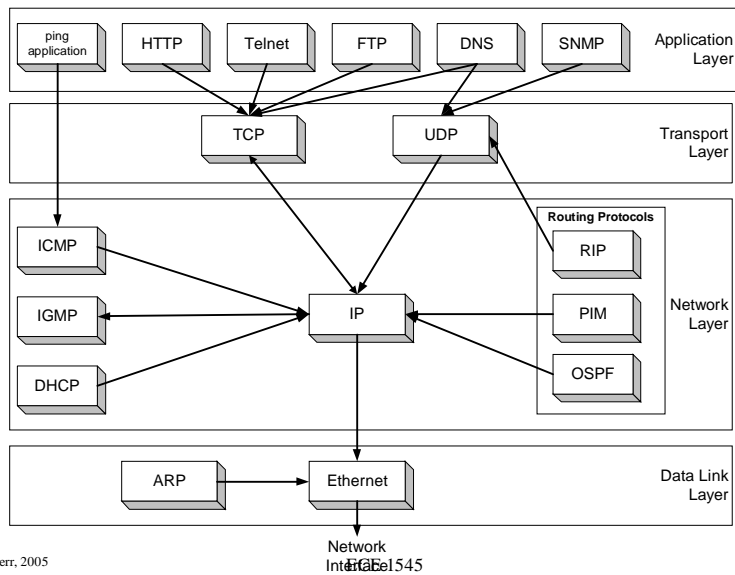
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# TCP/IP protocol suite

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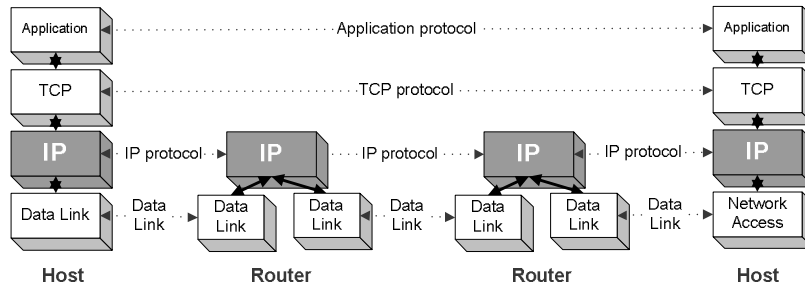
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## Assignment of Protocols to Layers



## Layers in routers and hosts

- IP is the highest layer protocol which is implemented at both routers and hosts

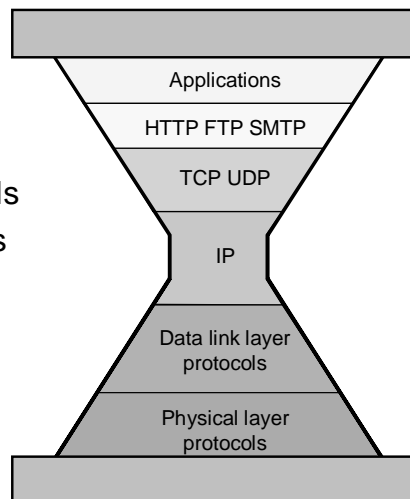


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## IP: The waist of the hourglass

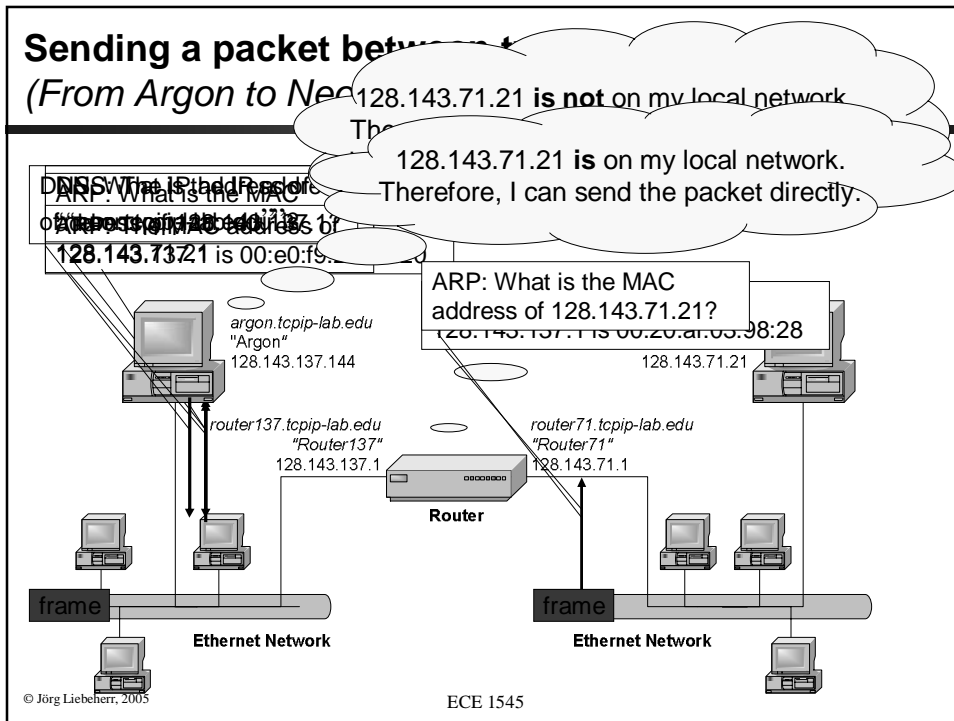
- **IP is the waist of the hourglass of the Internet protocol architecture**
- Multiple higher-layer protocols
- Multiple lower-layer protocols
- Only one protocol at the network layer.



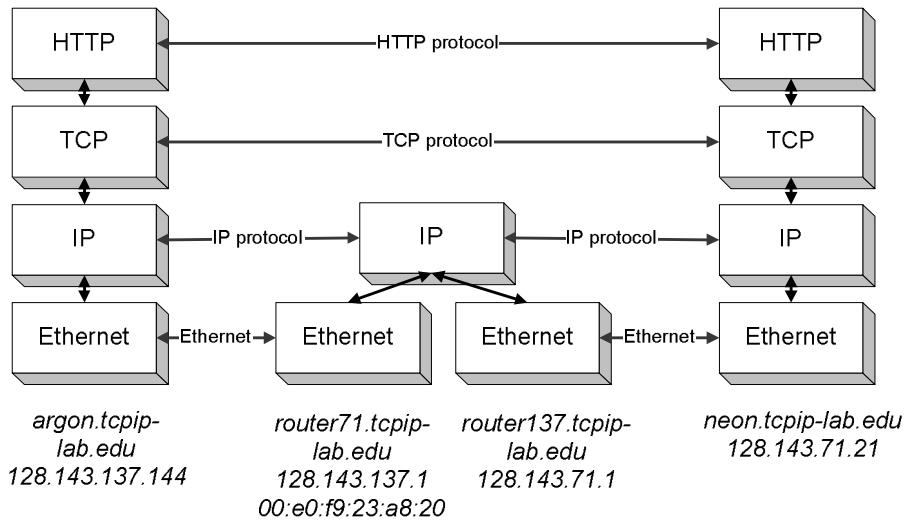
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# An example



## Layers in the Example



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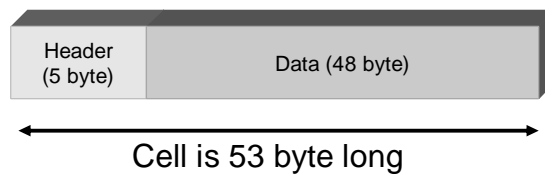
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## Case Study: ATM (+ MPLS)

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### ATM's Key Concepts

- **ATM uses Virtual-Circuit Packet Switching**
  - ATM can reserve capacity for a virtual circuit. This is useful for voice and video, which require a minimum level of service
  - Overhead for setting up a connection is expensive if data transmission is short (e.g., web browsing)
- **ATM packets are small and have a fixed sized**
  - Packets in ATM are called *cells*
  - Small packets are good for voice and video transmissions



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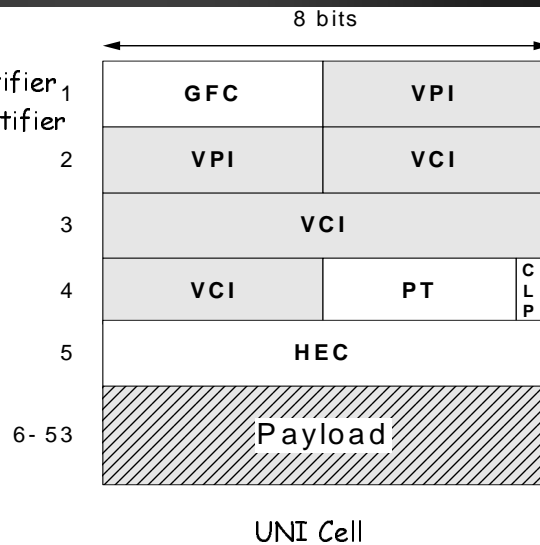
## 53 Byte Cells

- **Why 53 Bytes?**  
A 48 byte payload was the result of a compromise between a 32 byte payload and a 64 byte payload
- **Advantages**
  - Low packetization delay for continuous bit rate applications (video, audio)
  - Processing at switches is easier
- **Disadvantages**
  - High overhead (5 Bytes per 48)
  - Poor utilization at lower line rates links

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## ATM Cells

- 4-bit Generic flow control
- 8/12 bit Virtual Path Identifier<sub>1</sub>
- 16 bit Virtual Channel Identifier
- 3 bit Payload Type
- 1 bit Cell Loss Priority
- 8 bit Header Error Control
- 48 byte payload
- GFC field only in UNI cells

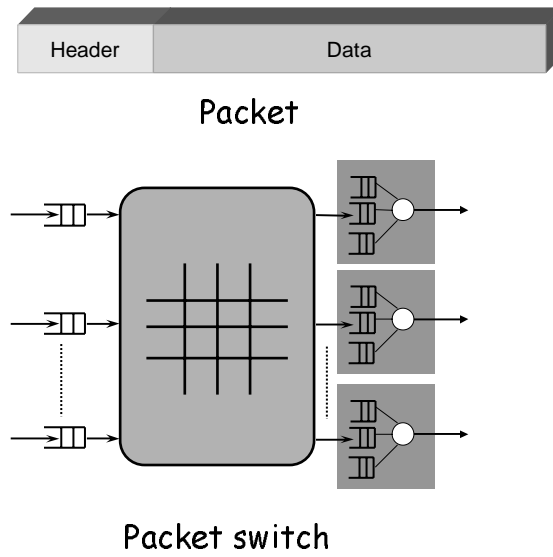


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# ATM Connections

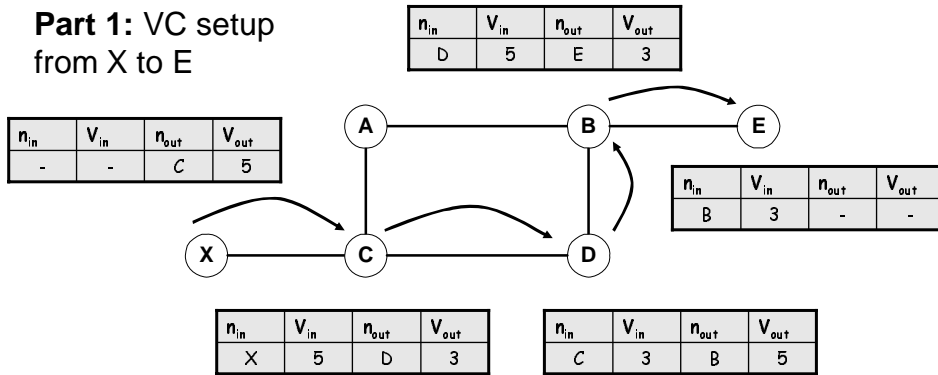
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## A Packet Switch



## Forwarding with VCs

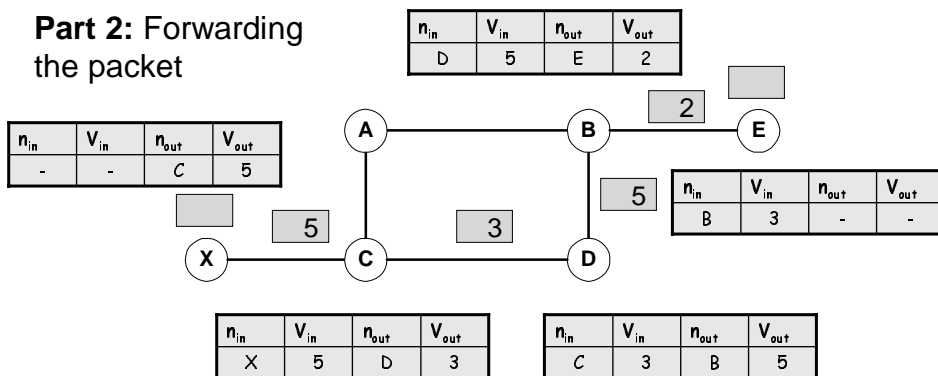
Part 1: VC setup  
from X to E



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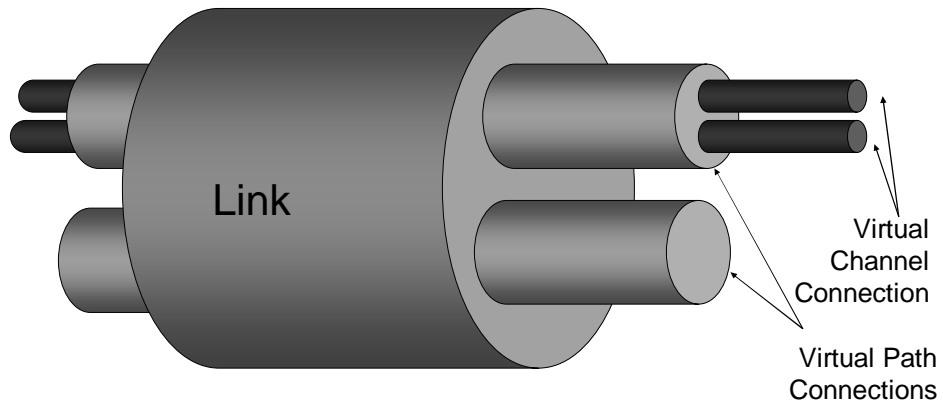
## Forwarding with VCs

Part 2: Forwarding  
the packet



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## Virtual Paths and Virtual Circuits

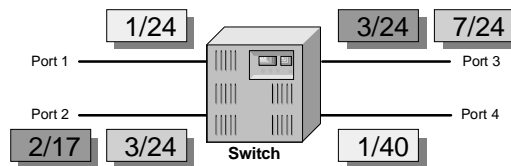


VPI identifies virtual path (8 or 12 bits)

VCI identifies virtual channel in a virtual path (16 bits)

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## VPI/VCI assignment at ATM switches



Routing Table of switch v

port	VPI/VCI	to	VPI/VCI
2	3/24	3	7/24
1	1/24	4	1/40
2	2/17	3	3/24

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# Multiprotocol Label Switching (MPLS)

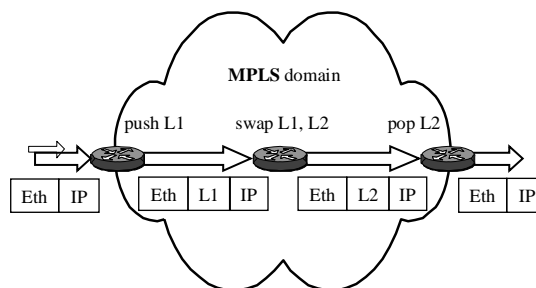
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## MPLS

- Provides Virtual Circuit Switching to IP networks
  - Design started in 1997 by IETF, RFC 3031 was released in 2001.
- Goal: Make IP networks faster

### Approach:

- Add a small label to packets at the ingress to the network
- Switch packets based upon these labels
- Label is removed by the egress router

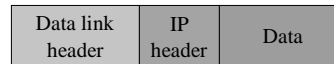


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## Labels in MPLS

- Label
  - Identifier (20 bits) for a Virtual Circuit
  - With Ethernet and IP: a label is contained in a "shim header"
  - A label can be pushed, popped, swapped by MPLS routers

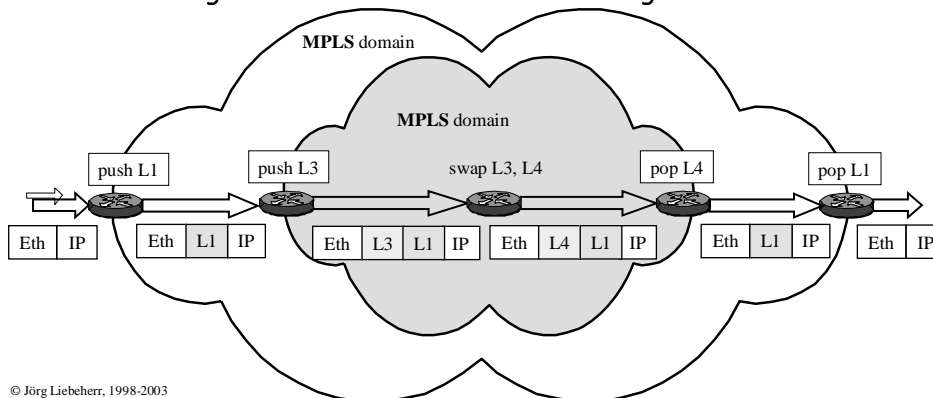
MPLS  
"shim header"



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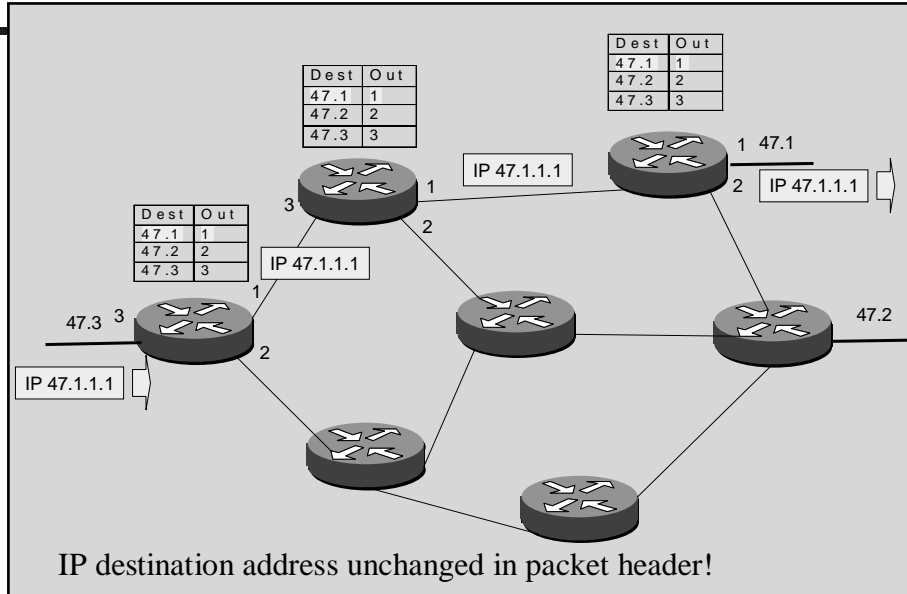
## Stacking of MPLS labels

- MPLS networks can be nested
- Multiple labels can be added
  - Push a label at each new ingress
  - Pop label at each egress
- Result is a generalization of VPI/VCI switching in ATM



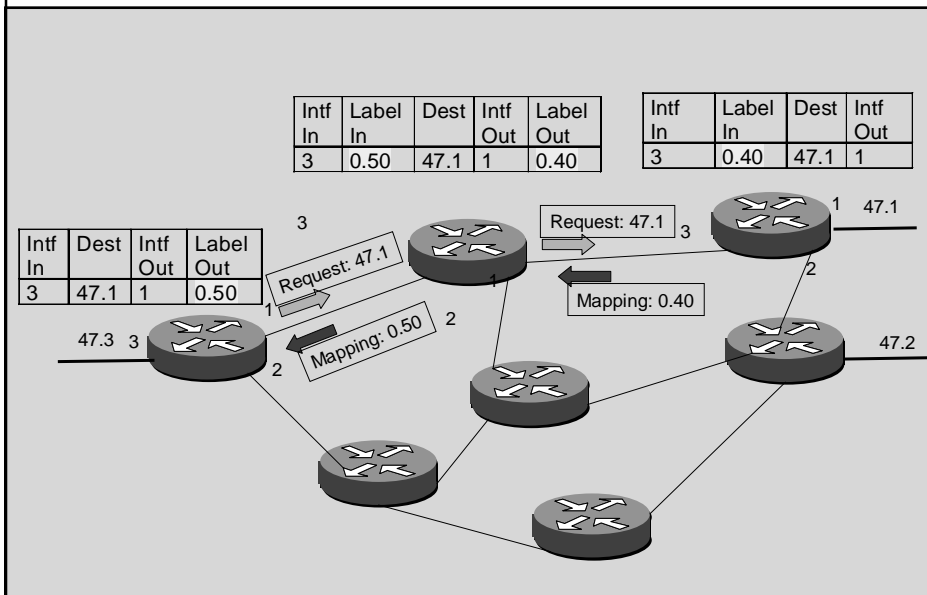
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## Regular IP Forwarding



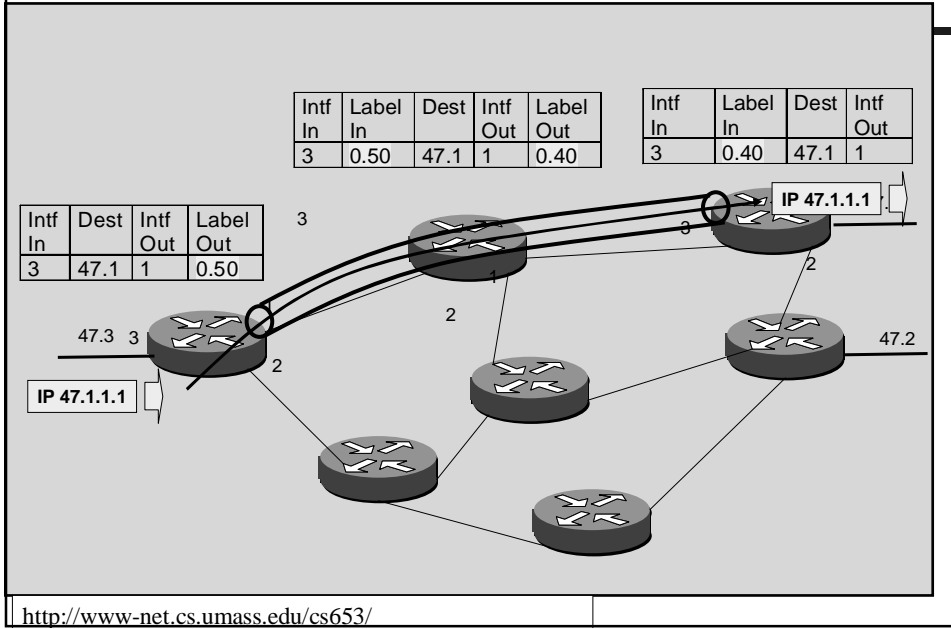
<http://www-net.cs.umass.edu/cs653/>

## MPLS Label Distribution



<http://www-net.cs.umass.edu/cs653/>

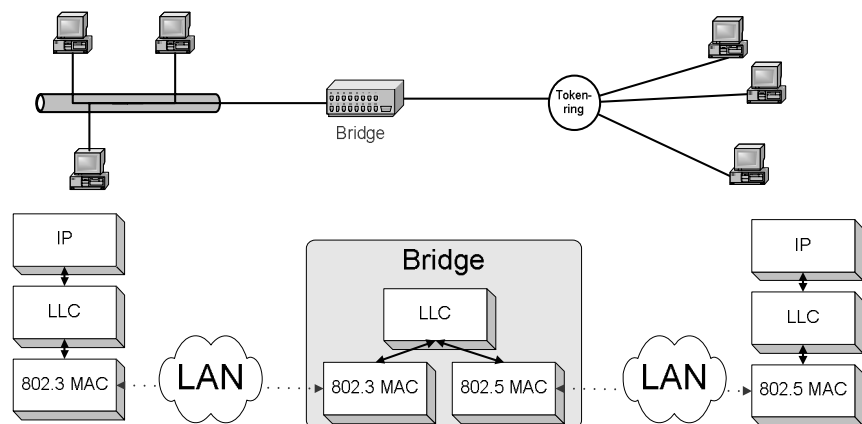
# Label Switched Path (LSP)



# LAN Switching

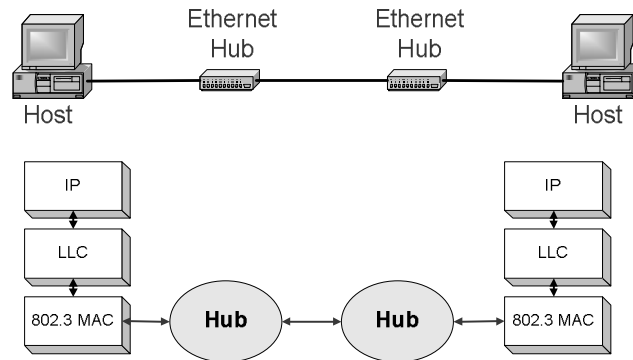
## Bridges/LAN switches

- A *bridge* or *LAN switch* is a device that interconnects two or more *Local Area Networks (LANs)* and forwards packets between these networks.
- Bridges/*LAN switches* operate at the Data Link Layer (Layer 2)



## Ethernet Hub

- Used to connect hosts to Ethernet LAN and to connect multiple Ethernet LANs
- Collisions are propagated



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## Terminology: Bridge, LAN switch, Ethernet switch

There are different terms to refer to a data-link layer interconnection device:

- The term **bridge** was coined in the early 1980s.
- Today, the terms **LAN switch** or (in the context of Ethernet) **Ethernet switch** are used.

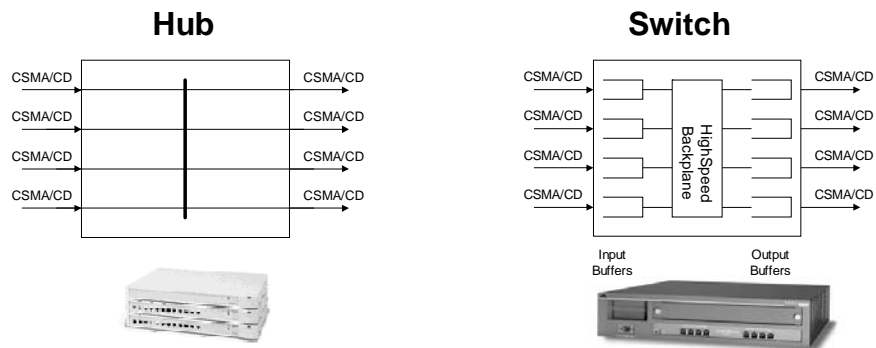
### Convention:

- Since many of the concepts, configuration commands, and protocols for LAN switches were developed in the 1980s, and commonly use the old term *bridge*, we will, with few exceptions, refer to LAN switches as bridges.

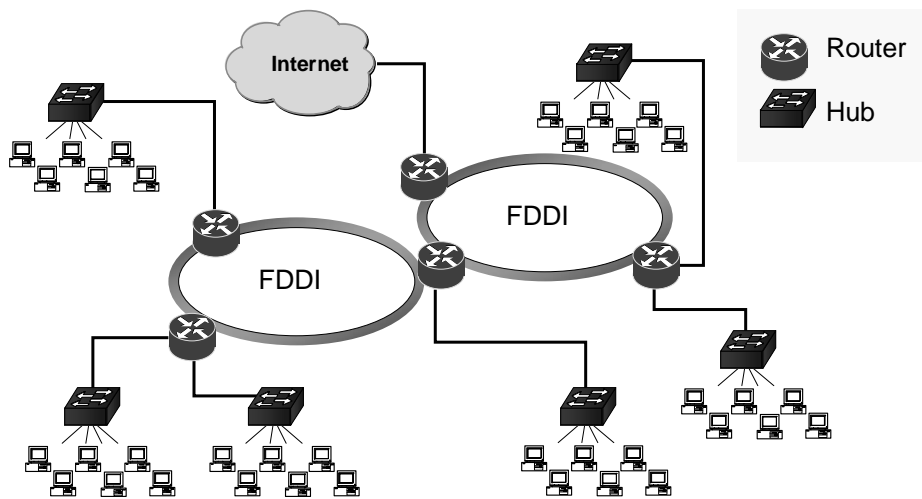
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## Ethernet Hubs vs. Ethernet Switches

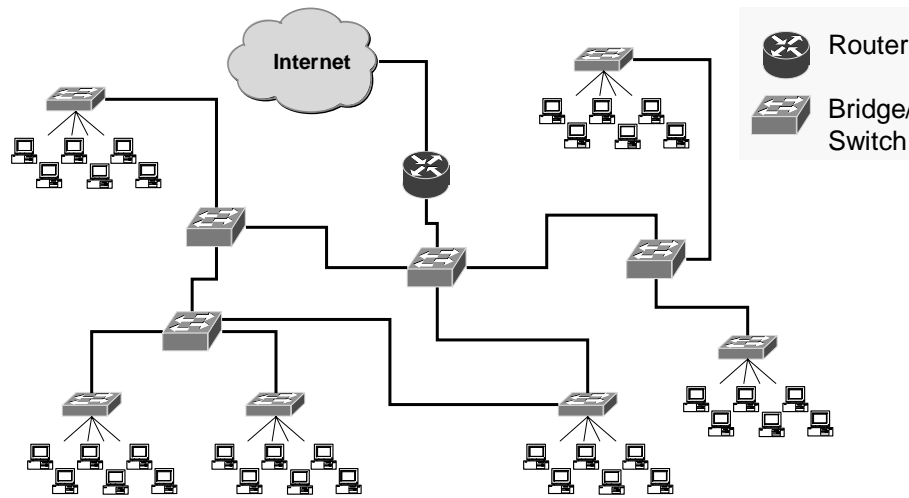
- An **Ethernet switch** is a packet switch for Ethernet frames
  - Buffering of frames prevents collisions.
  - Each port is isolated and builds its own collision domain
- An **Ethernet Hub** does not perform buffering:
  - Collisions occur if two frames arrive at the same time.



## A Routed Enterprise Network



## A Switched Enterprise Network



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### (1) Frame Forwarding

- Each bridge maintains a **MAC forwarding table**
- Forwarding table plays the same role as the routing table of an IP router
- Entries have the form ( MAC address, port, age), where

**MAC address:** host name or group address  
**port:** port number of bridge  
**age:** aging time of entry (in seconds)

with interpretation:

a machine with **MAC address** lies in direction of the **port** number from the bridge. The entry is **age** time units old.

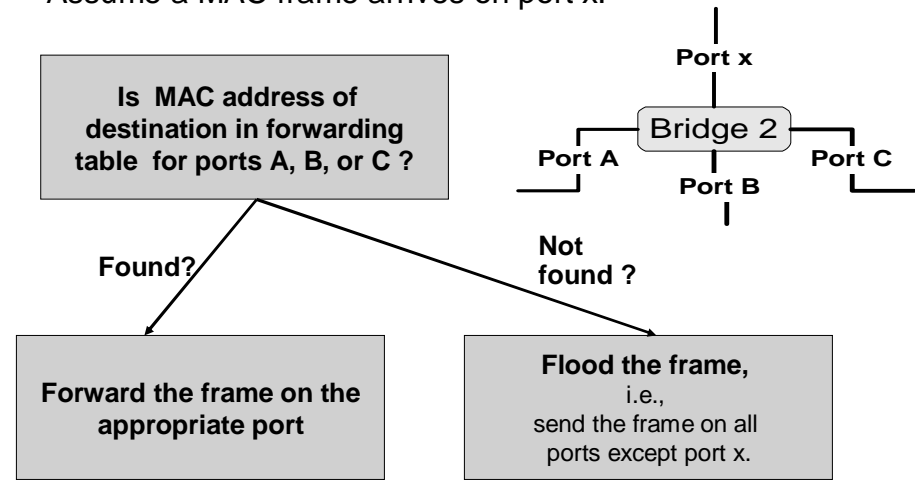
MAC forwarding table →

MAC address	port	age
a0:e1:34:82:ca:34	1	10
45:6d:20:23:fe:2e	2	20

8

## (1) Frame Forwarding

- Assume a MAC frame arrives on port x.

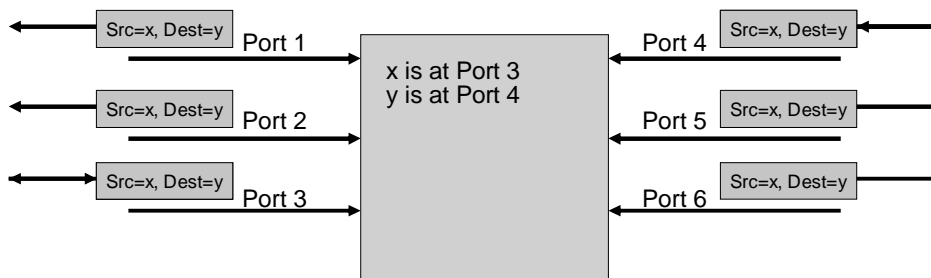


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## (2) Address Learning

- Routing tables entries are set automatically with a simple heuristic:

The source field of a frame that arrives on a port tells which hosts are reachable from this port.

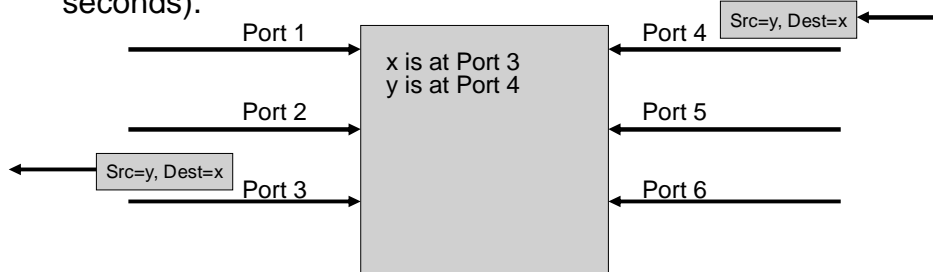


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## (2) Address Learning

Learning Algorithm:

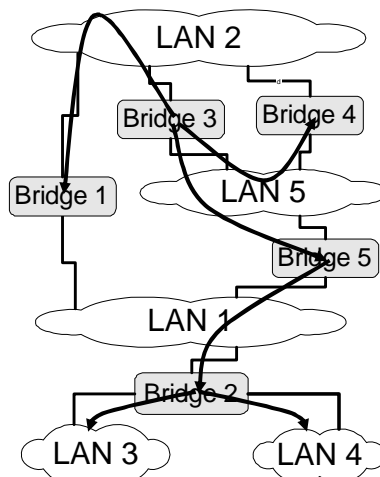
- For each frame received, the source stores the source field in the forwarding database together with the port where the frame was received.
- All entries are deleted after some time (default is 15 seconds).



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## Spanning Tree Protocol (IEEE 802.1d)

- The Spanning Tree Protocol (SPT) is a solution to prevent loops when forwarding frames between LANs
- The SPT is standardized as the IEEE 802.1d protocol
- The SPT organizes bridges and LANs as spanning tree in a dynamic environment
  - Frames are forwarded only along the branches of the spanning tree
  - Note: Trees don't have loops
- Bridges that run the SPT are called transparent bridges
- Bridges exchange messages to configure the bridge (Configuration Bridge Protocol Data Unit or BPDUs) to build the tree.



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