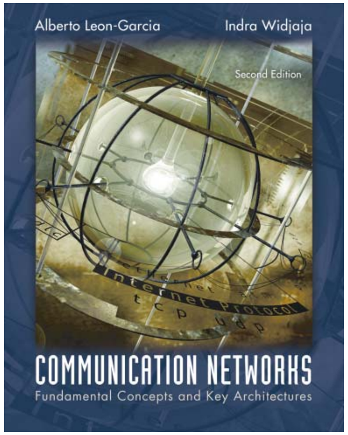
Chapter 1
Communication Networks and Services



Computer Networks & Packet Switching

Computer Network Evolution Overview

1950s - 1960s: Terminal-Oriented Computer Networks

1960s – 1970s: Computer-to-Computer Networks:

the ARPANET – first Wide Area Network (WAN)

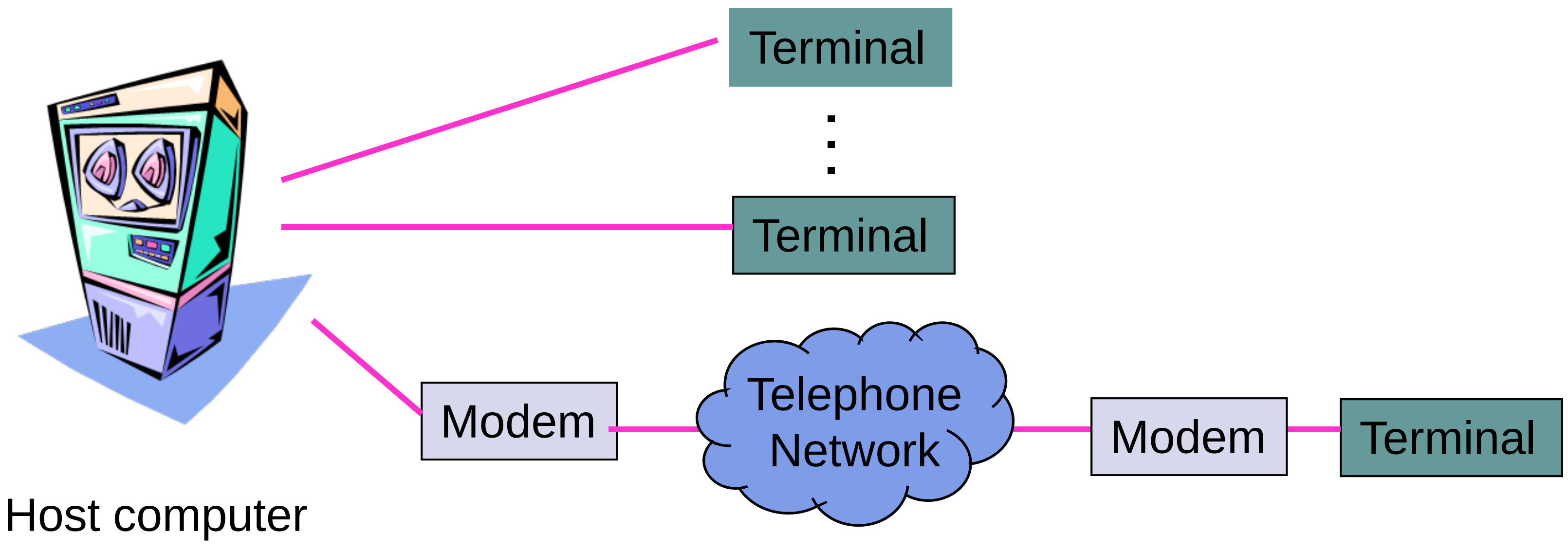
1980s: Local Area Networks (LANs)

1980s: The Internet

most superior telecommunication network

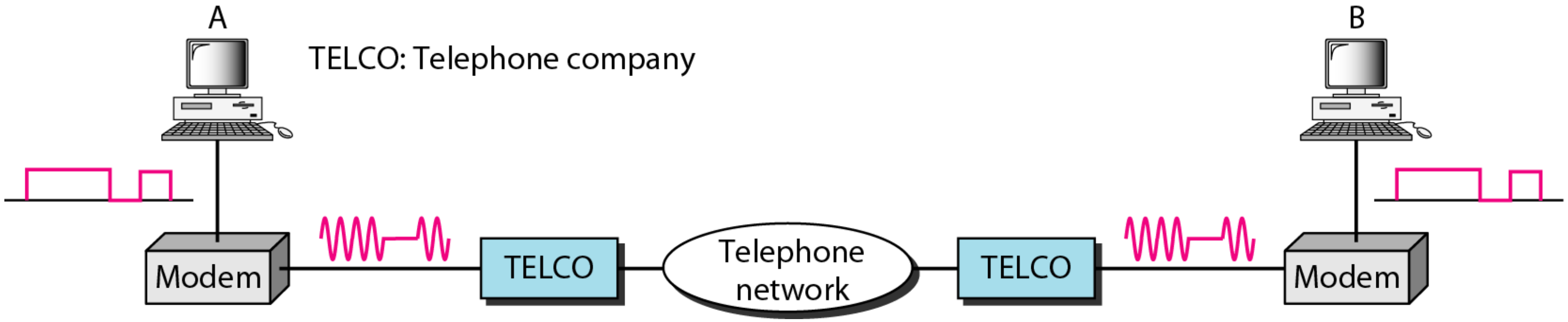
Terminal-Oriented Networks

- Early computer systems very expensive
- Time-sharing methods allowed multiple terminals to share local computer
- Remote access via telephone modems



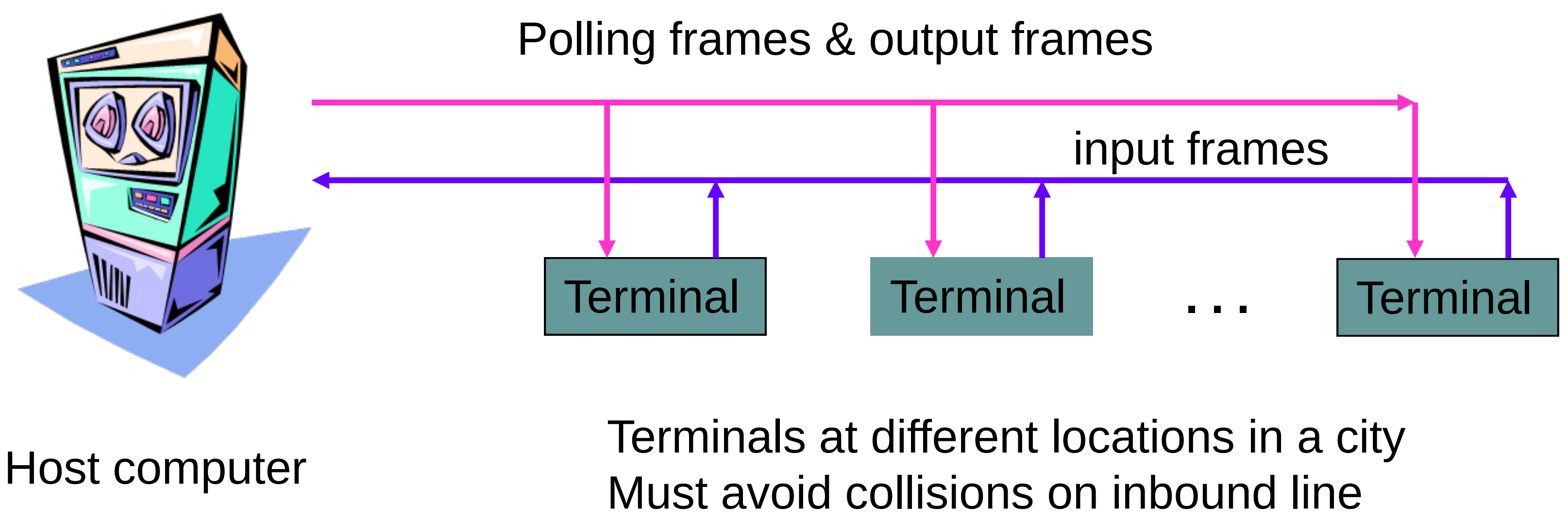
Terminal-Oriented Networks

Example **[modulation / demodulation]**



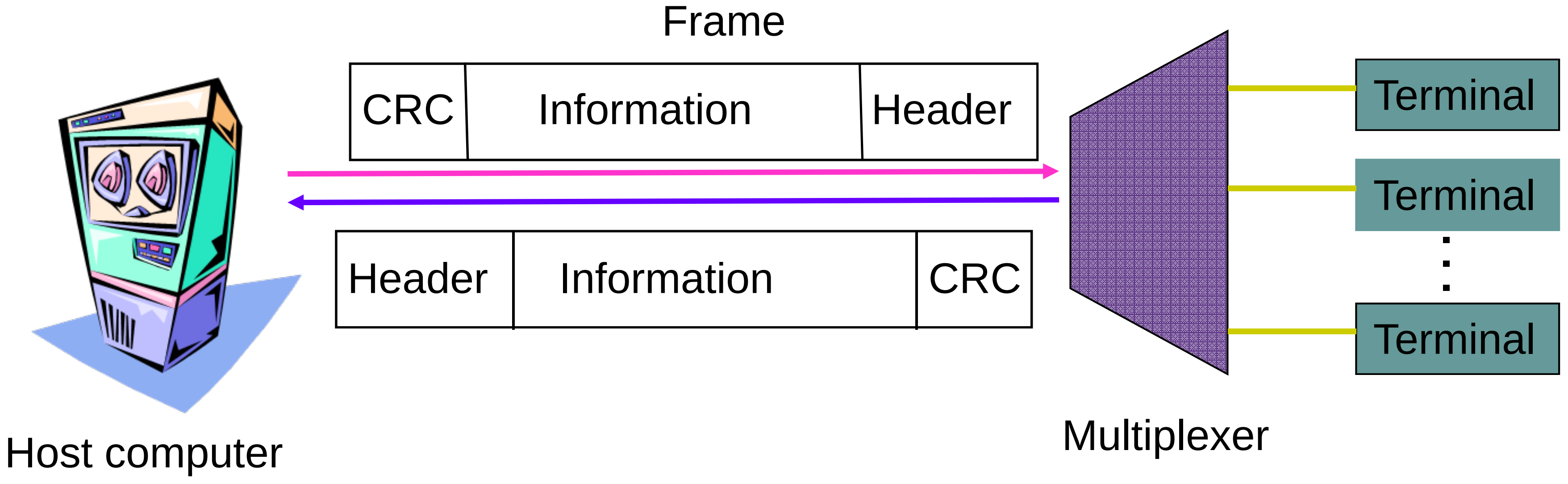
Medium Access Control

- Dedicated communication lines were expensive
- Terminals generated messages sporadically
- Frames carried messages to/from attached terminals
- Address in frame header identified terminal
- *Medium Access Controls* for sharing a line were developed
- Example: Polling protocol on a multidrop line



Statistical Multiplexing

- Statistical multiplexer allows a line to carry *frames* that contain messages to/from multiple terminals
- Frames are buffered at *multiplexer* until line becomes available, i.e. store-and-forward
- *Address* in frame header identifies terminal
- Header carries other *control* information



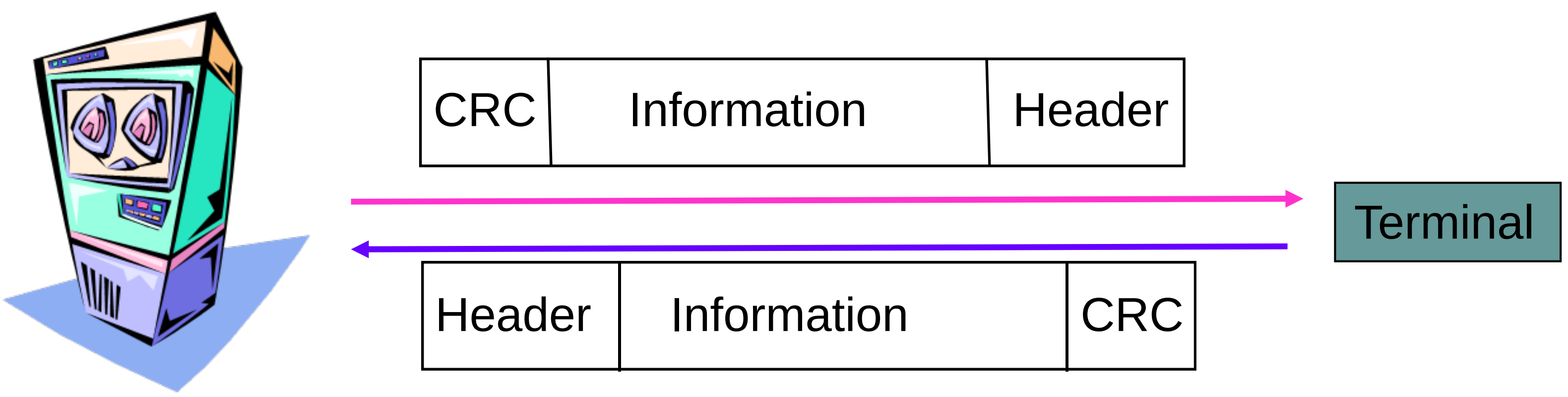
Error Control Protocol

- Communication lines introduced errors
- Error checking codes used on frames
  - “Cyclic Redundancy Check” (CRC) “check bits”

(1) CRC is calculated based on frame header and payload

(2) CRC is appended to frame

(3) if receiver detects error, retransmission is requested



1950s - 1960s: Terminal-Oriented Computer Networks

1960s – 1970s: Computer-to-Computer Networks:
the ARPANET – first Wide Area Network (WAN)

1980s: Local Area Networks (LANs)

1980s: The Internet

Computer-to-Computer Networks

- As cost of computing dropped, terminal-oriented networks viewed as too inflexible and costly
- Need to develop flexible computer networks
  - Interconnect computers as required
  - Support many applications
- Application Examples
  - File transfer between arbitrary computers
  - Execution of a program on another computer
  - Multiprocess operation over multiple computers

Packet Switching

- Network should support multiple applications
  - Transfer arbitrary message size
  - Low delay for interactive applications
  - But in store-and-forward operation, long messages induce high delay on interactive messages
- Packet switching introduced
  - Network transfers packets using store-and-forward
  - Packets have maximum length
  - Break long messages into multiple packets
- ARPANET testbed led to many innovations

ARPANET Packet Switching

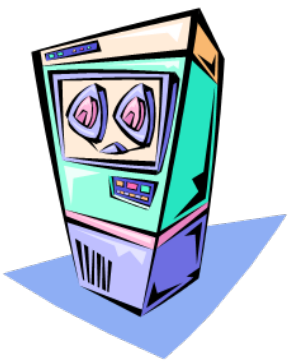
Host generates message

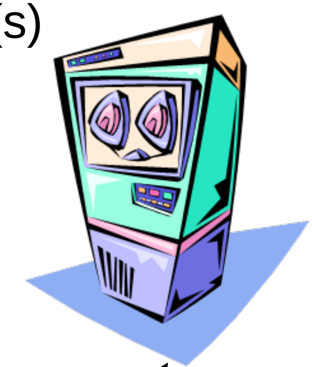
Source packet switch converts message to packet(s)

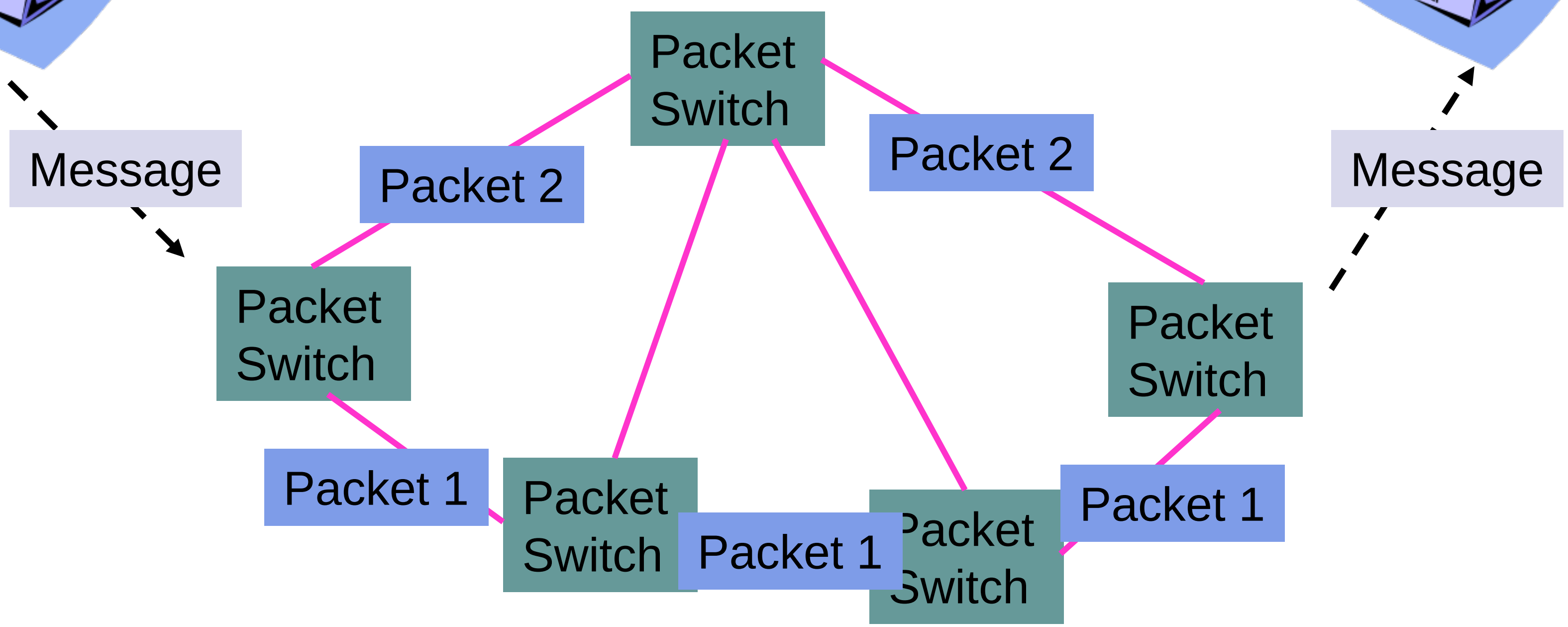
Packets transferred independently across network

Destination packet switch reasembles message

Destination packet switch delivers message







ARPANET Routing

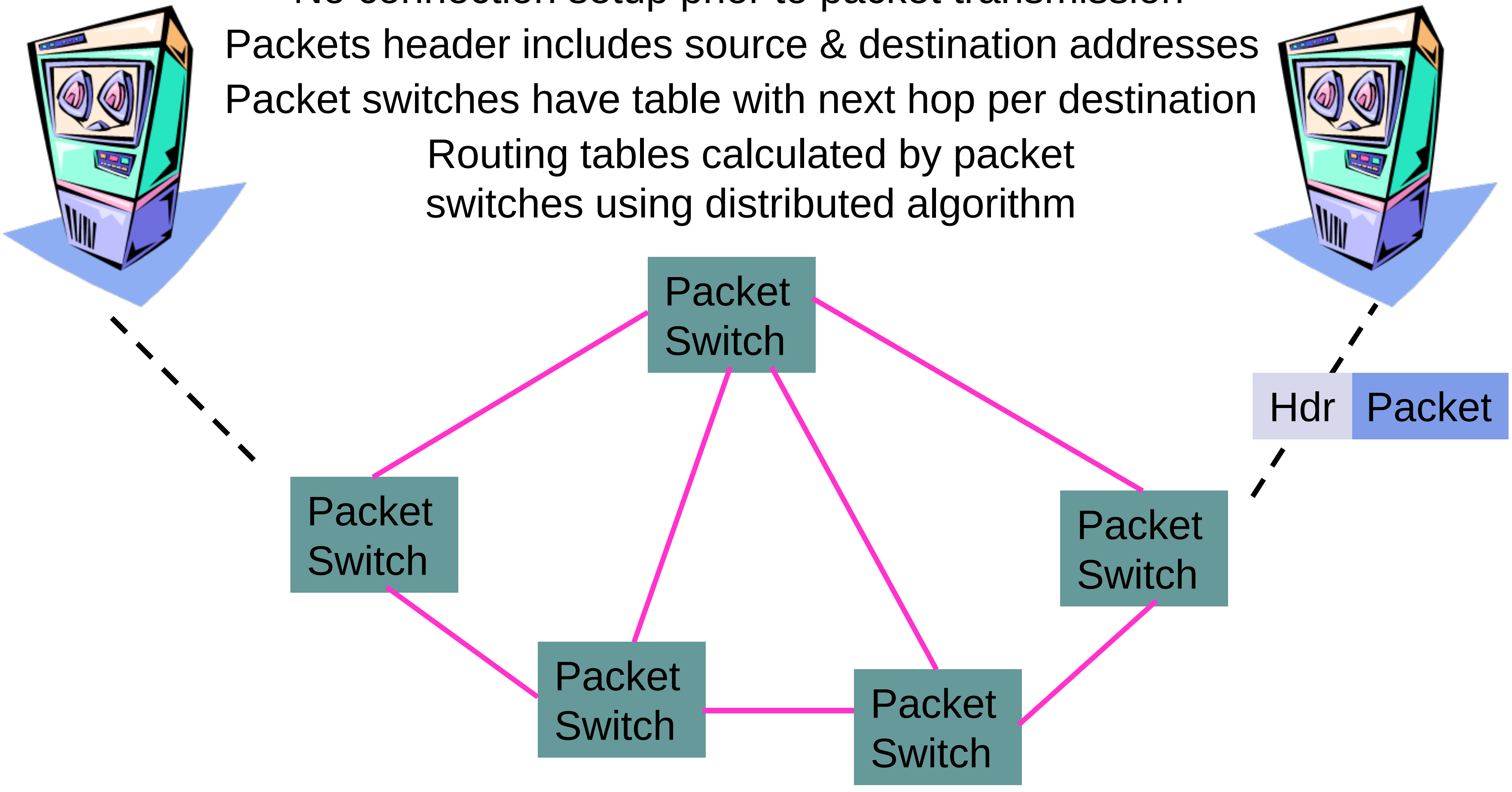
Routing is highly nontrivial in mesh networks

No connection setup prior to packet transmission

Packets header includes source & destination addresses

Packet switches have table with next hop per destination

Routing tables calculated by packet switches using distributed algorithm

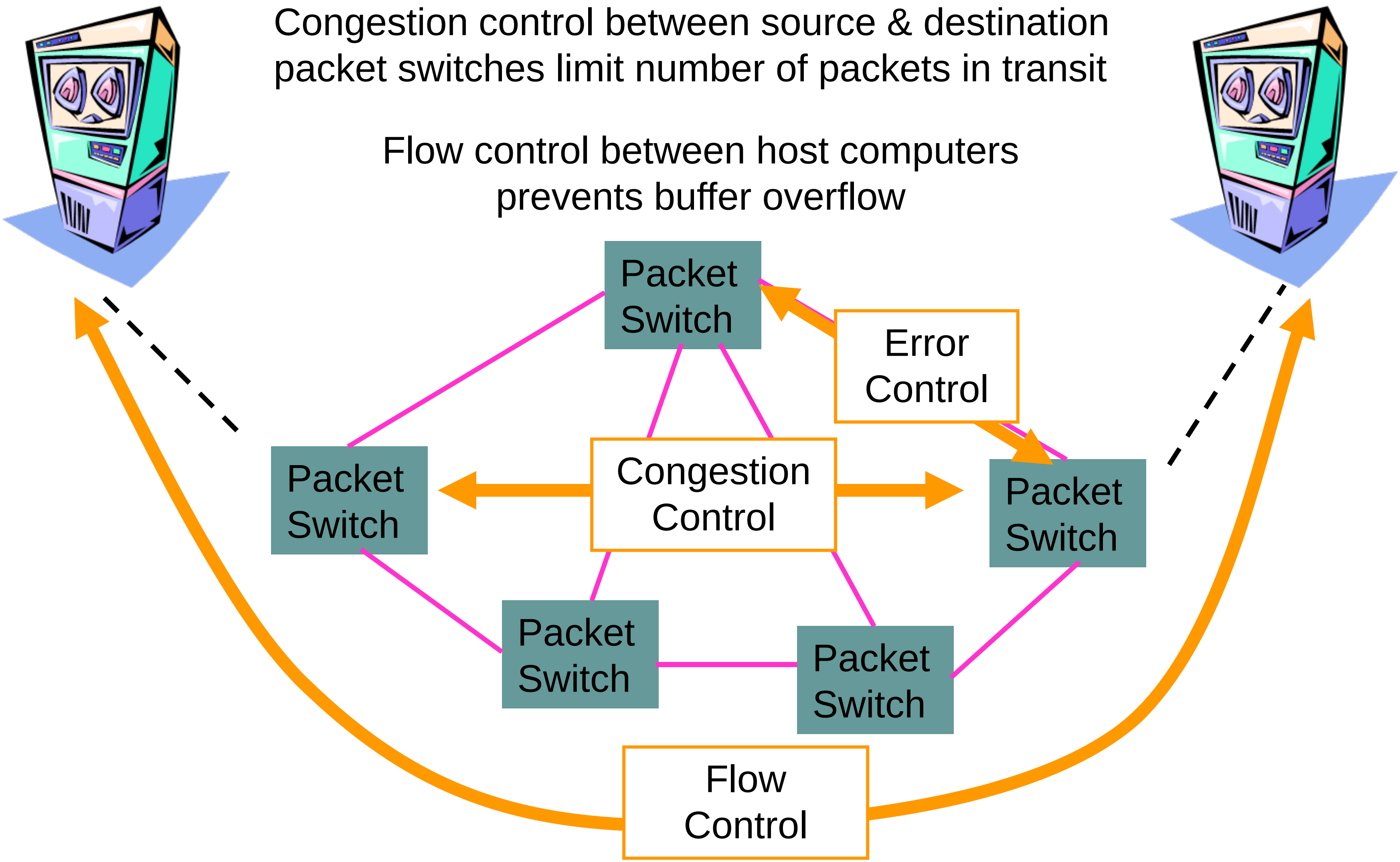


Other ARPANET Protocols

Error control between adjacent packet switches

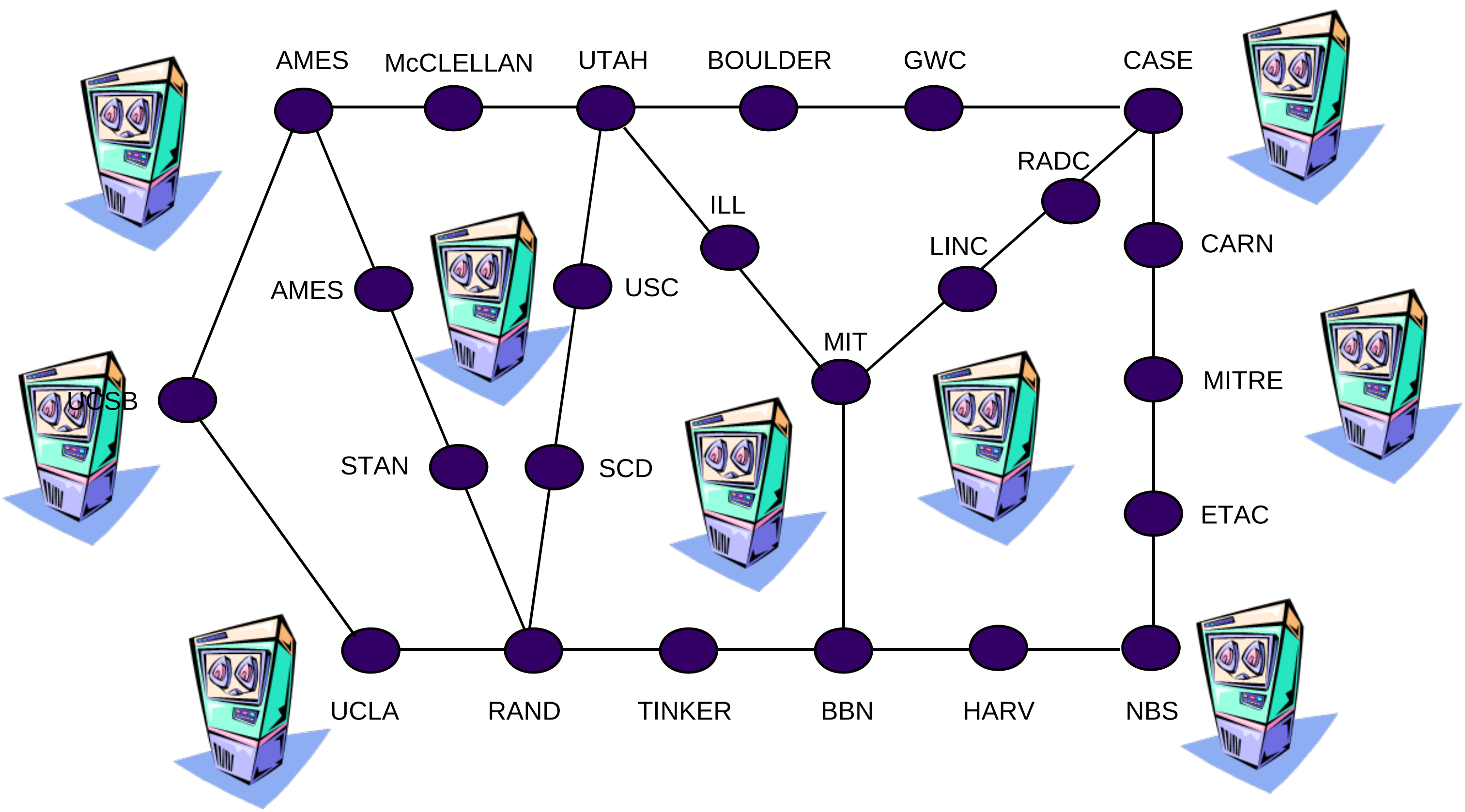
Congestion control between source & destination packet switches limit number of packets in transit

Flow control between host computers prevents buffer overflow



ARPANET Applications

- ARPANET introduced many new applications
- Email, remote login, file transfer, …
- Intelligence at the ***edge***



1950s - 1960s: Terminal-Oriented Computer Networks

1960s – 1970s: Computer-to-Computer Networks:

the ARPANET – first Wide Area Network (WAN)

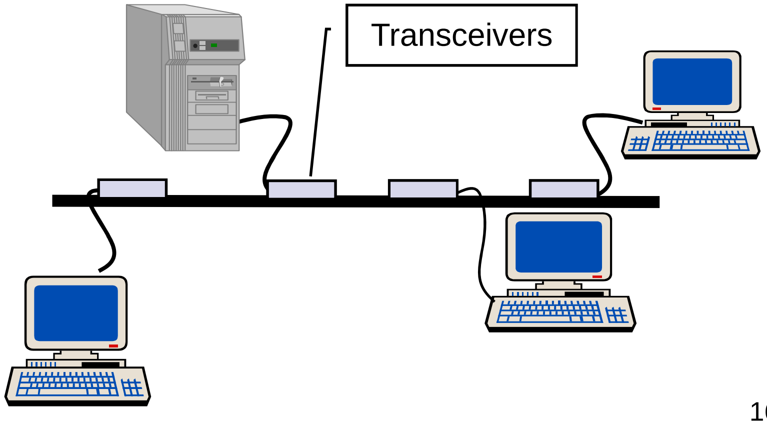
1980s: Local Area Networks (LANs)

1980s: The Internet

Local Area Networks

LAN History

- in 1980s affordable computers became available
- subsequently, need for low-cost, high-speed, and low error-rate networks arose
  - to interconnect local workstations over small radius < 1km
  - to enable sharing of local resources (printers, servers, etc.)
- complex packet switching, congestion and flow control were unnecessary
- variety of LAN topologies emerged, including: bus, ring



Local Area Networks (cont.)

Bus Topology (Ethernet)

one long cable, so-called backbone, links all devices in the network

- each workstation connects to backbone through Network Interface Card (NIC); each NIC has globally unique address
- data frames are broadcast into coaxial cable
- receive: NIC listens to medium for frames with its address
- send: NIC listens to medium for presence of ongoing transmission – if no transmission is found, send frame
- collision: if frame collides with somebody else's frame, abort transmission and retry later

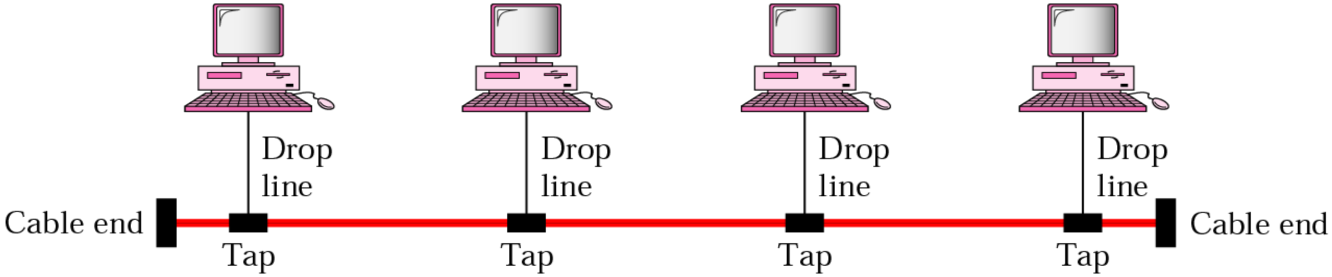
Local Area Networks (cont.)

Bus Topology (Ethernet)

- advantages: simple & inexpensive installation
- disadvantages: 1) backbone = single point of failure

  2) collisions ⇒ diminishing capacity

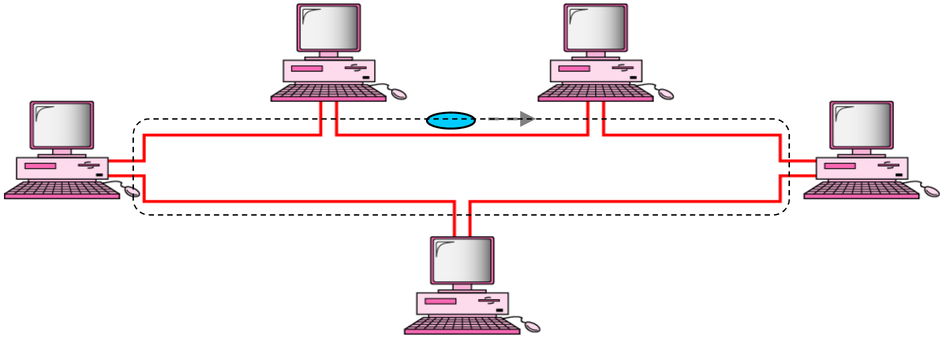
- if two or more devices transmit simultaneously their signals will interfere



Local Area Networks (cont.)

Ring Topology – each device has a dedicated point-to-point connection only with the two devices on either side of it

- a small frame – token – circulates around the ring; only the station that possesses the token is allowed to transmit at any given time
- signal is passed along the ring in one direction, from device to device, until it reaches its destination
- advantages: fairness in access / effective use of bandwidth– token-passing provides each station with a turn to transmit
- disadvantages: entire network will fail if there is a failure in any transmission link or in the mechanism that relays the token



1950s - 1960s:	Terminal-Oriented Computer Networks
1960s – 1970s:	Computer-to-Computer Networks: the ARPANET – first Wide Area Network (WAN)
1980s:	Local Area Networks (LANs)
1980s:	The Internet

The Internet

Internet = Internetwork – two or more interconnected networks – network of networks

The Internet: Past

- LANs that emerged in 1970s were different in terms of their underlying technology and operation
- a protocol that would enable communication across multiple dissimilar networks was needed
  - "higher level of abstraction" protocol
- Internet Protocol / Addressing were soon developed and enabled creation of a single global internetwork

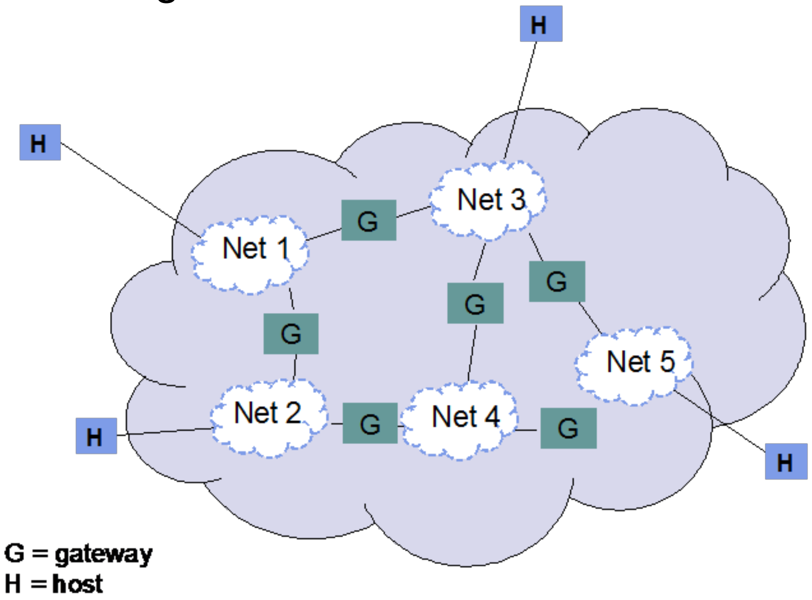
The Internet: Present

- spread over 200 countries
- made up of 100,000s of interconnected networks, 10,000,000s of interconnected hosts, and 100,000,000s of users
- still grows exponentially …

The Internet (cont.)

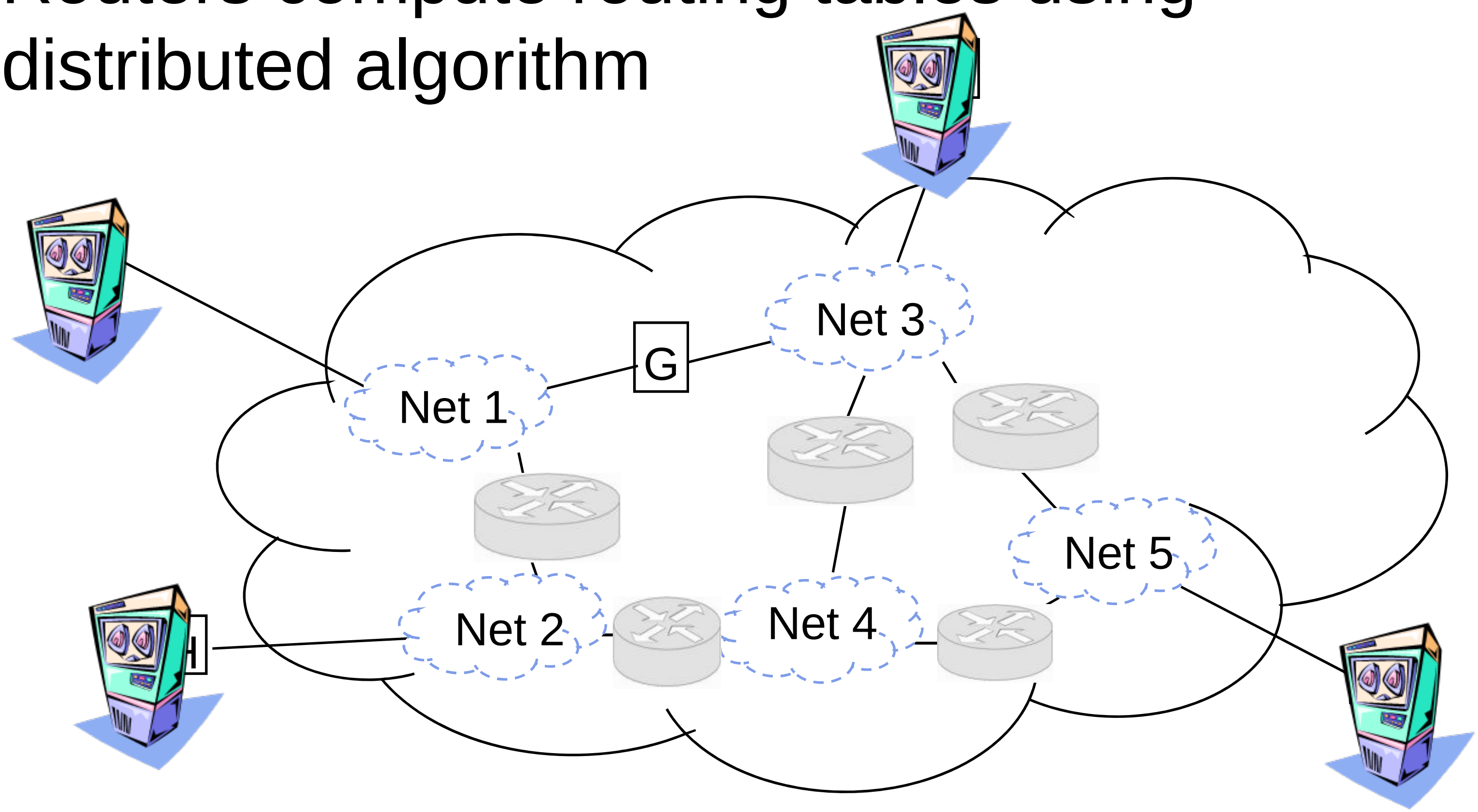
IP Network = the Internet

- each component network must contain special packet switch, gateway / router, through which it interconnects with rest of the Internet
- host computers place data in IP packets (data + IP header) and deliver them to nearest router
- router, with help of other routers, attempts to forward packet across the Internet
- "best effort service" – IP provides no mechanism to deal with packet loss, corruption, reordering



Addressing & Routing

- Hierarchical address: Net ID + Host ID
- IP packets routed according to Net ID
- Routers compute routing tables using distributed algorithm

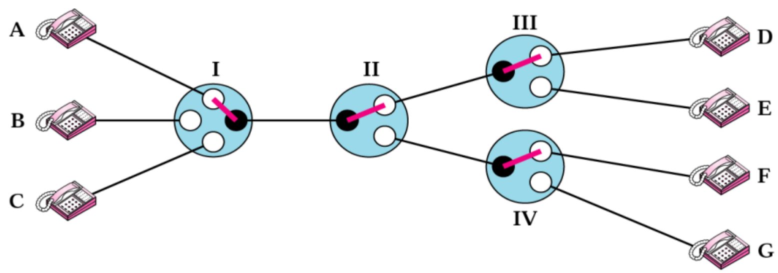


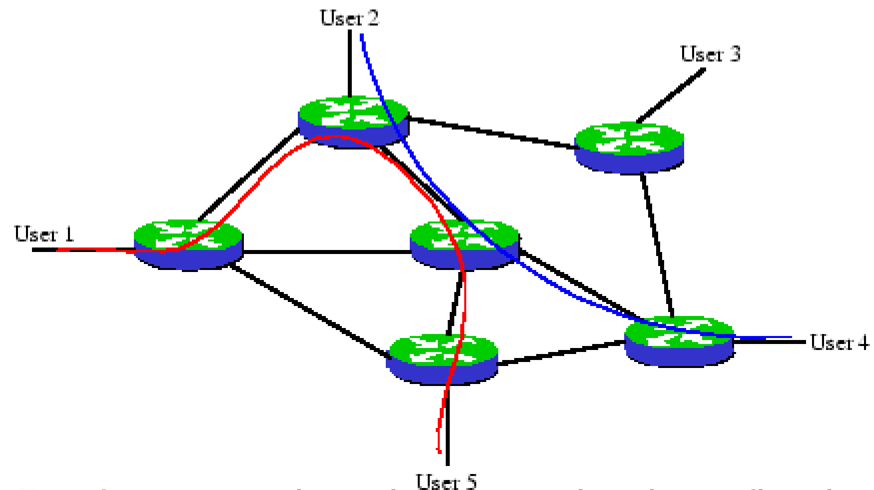
Names and IP Addresses

- Routing is done based on 32-bit IP addresses
- Dotted-decimal notation
  - 128.100.11.1
- Hosts are also identified by name
  - Easier to remember
  - Hierarchical name structure
  - cse.yorku.ca
- Domain Name System (DNS) provided conversion between names and addresses

Packet vs. Circuit Switching

Circuit-Switched Networks (telephone networks)





Advantages

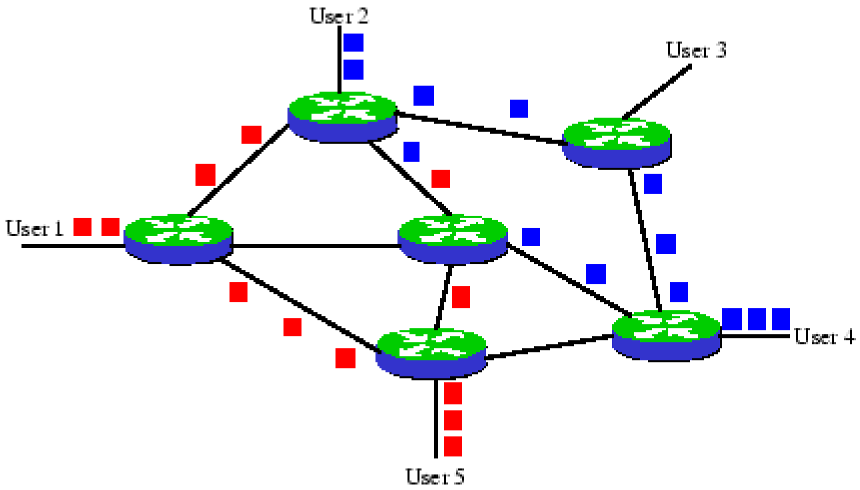
- guaranteed Quality of Service – data is transmitted at fixed (guaranteed) rate; delay at nodes is negligible

Disadvantages

- circuit establishment delay – circuit establishment introduces 'initial delay'
- inefficient use of capacity – channel capacity is dedicated for the duration of a connection, even if no data is being transferred (e.g. silent periods in speech)
- network complexity – end-to-end circuit establishment and bandwidth allocation requires complex signaling software to coordinate operation of switches

Packet vs. Circuit Switching (cont.)

Packet-Switched Networks (the Internet)



Advantages

- greater line efficiency – network links are dynamically shared by many packets / connections
- no blocked traffic – packets are accepted even under heavy traffic, but delivery delay may increase

Disadvantages

- variable delay – each node introduces additional variable delay due to processing and queuing
- overhead – to route packets through a packet-switching network, overhead information including the address of destination and/or sequence information must be added to each packet