

Networking

- Inter-processes communication across machines enables new applications
- Starting in 1960s machines could talk directly to each other over a telephone line using modems
- Connecting multiple machines to a shared network required the development of routers
- Network communication is an expected service of modern OSes

How do processes communicate over a shared network?



First ARPANET router, 1969.

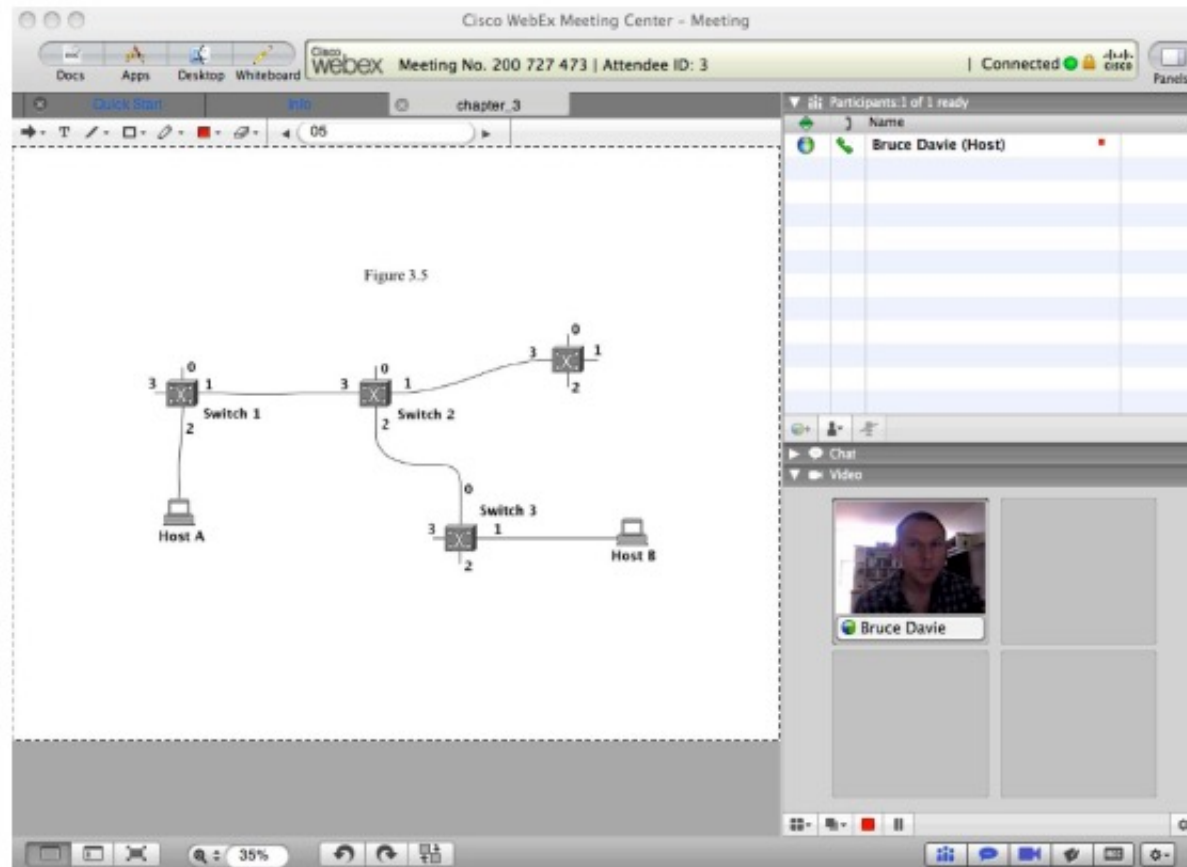
Key Concepts

- Protocols
 - Devices on the network need to speak the same language
- Layering
 - Multiple layers of protocols/interfaces to deal with different aspects (levels of abstraction)
 - Key to managing complexity
- Resource Allocation
 - Similar to OS (single machine) resource allocation problem
 - Limited buffer memory, bandwidth, paths, etc.
 - Unlike single machine allocation, decisions must now be made across multiple machines, distributed and centralized algorithms possible
- Naming
 - How to name networked devices?
 - How to locate a device by its name?

Applications

- Most people know about the Internet (a computer network) through applications
 - World Wide Web
 - Email
 - Online Social Network
 - Streaming Audio Video
 - File Sharing
 - Instant Messaging
 - ...

Example of an application



A multimedia application including video-conferencing

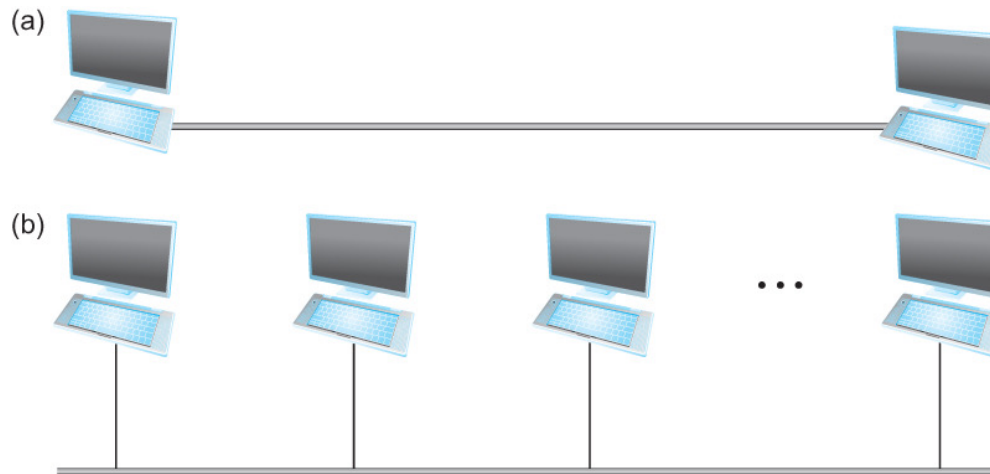
Application Level Protocols

- **Application-level protocol** is a shared language between distributed processes of a particular application
 - WWW (world wide web)
 - HTTP (hypertext transfer protocol)
 - Used for viewing and sending data to web sites
 - Email
 - SMTP (simple mail transfer protocol)
 - Used for transmitting email
 - DNS (domain name service)
 - DNS protocol
 - Used for looking up the server address of a domain name
 - SSH (Secure Shell)
 - SHS protocol
 - Used to securely control a shell on a remote machine
- May be different programs participating in an application
 - For example: Putty on Windows connecting to OpenSSH server on Linux

Application Protocol Example

- Applications may require multiple protocols, for example, a browser connecting to a web server shown below
- URL
 - Uniform resource locator
 - <http://www.cs.princeton.edu/~llp/index.html>
- HTTP
 - Hyper Text Transfer Protocol
- TCP
 - Transmission Control Protocol
- 17 messages for one URL request
 - 6 to find the IP (Internet Protocol) address
 - 3 for connection establishment of TCP
 - 4 for HTTP request and acknowledgement
 - Request: I got your request and I will send the data
 - Reply: Here is the data you requested; I got the data
 - 4 messages for tearing down TCP connection

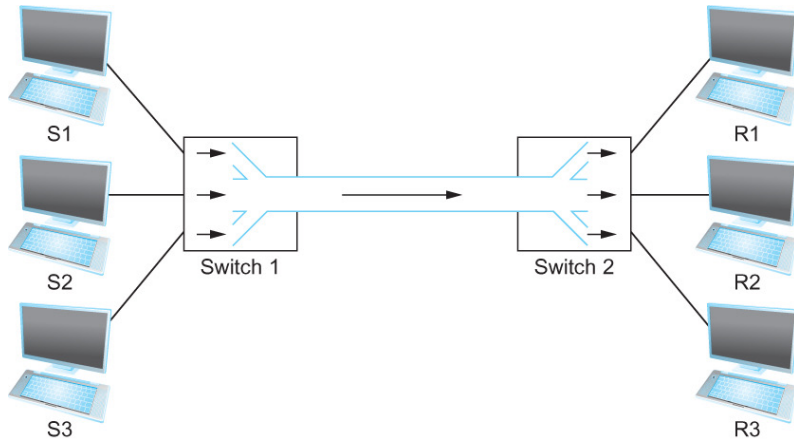
Connectivity



- (a) Point-to-point
(b) Multiple access

- **Connectivity terminology**
 - **Nodes** – computers, devices, routers...
 - **Link** – physical connection between nodes
 - **Point-to-point** – 2 nodes on 1 link
 - **Multiple access** – multiple nodes on 1 link
 - **Scale** – designed to support growth to an arbitrarily large size

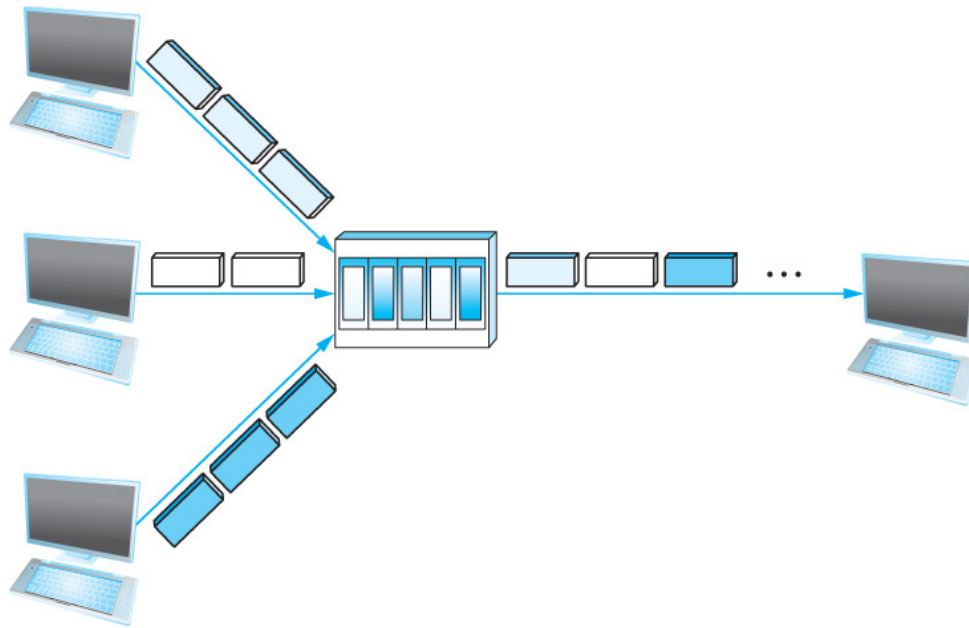
Cost-Effective Resource Sharing



Multiplexing multiple logical flows
over a single physical link

- Resource: links and nodes
- How to share a link?
 - Multiplexing
 - De-multiplexing
 - Synchronous Time-division Multiplexing
 - Time slots/data transmitted in predetermined slots

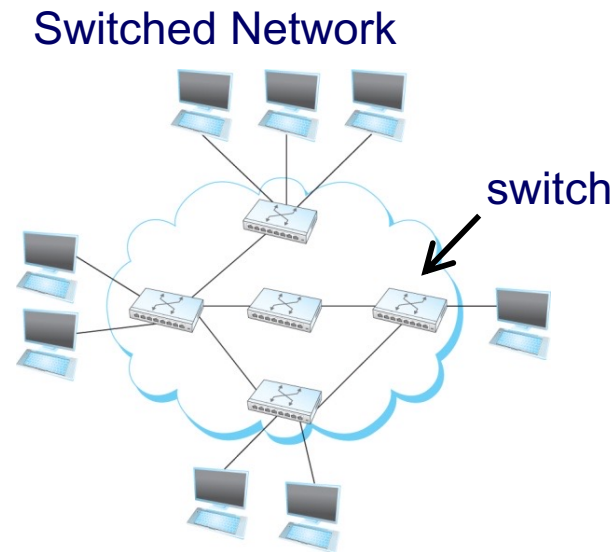
Cost-Effective Resource Sharing



A switch multiplexing packets from multiple sources onto one shared link

- FDM: Frequency Division Multiplexing
- Statistical Multiplexing
 - Data is transmitted based on demand of each flow.
 - Packets are small units of data (think of them as jobs)
 - Routers forward packets based on policies (just like scheduler policies): FIFO, Round-Robin, Priority (e.g, Quality-of-Service (QoS))
 - Need to deal with congestion – how to avoid one router getting more traffic than it can handle?

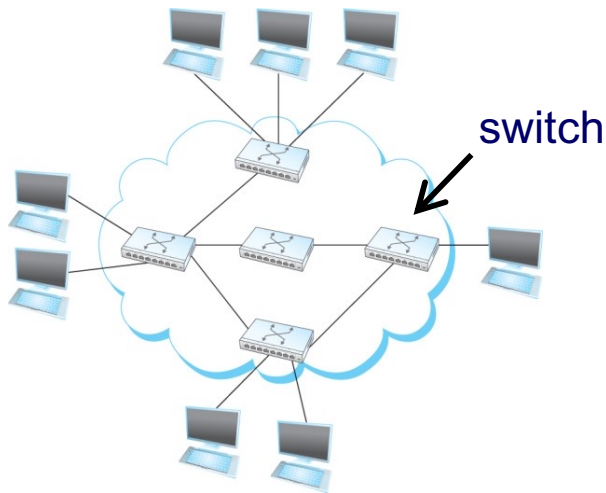
Connectivity (cont.)



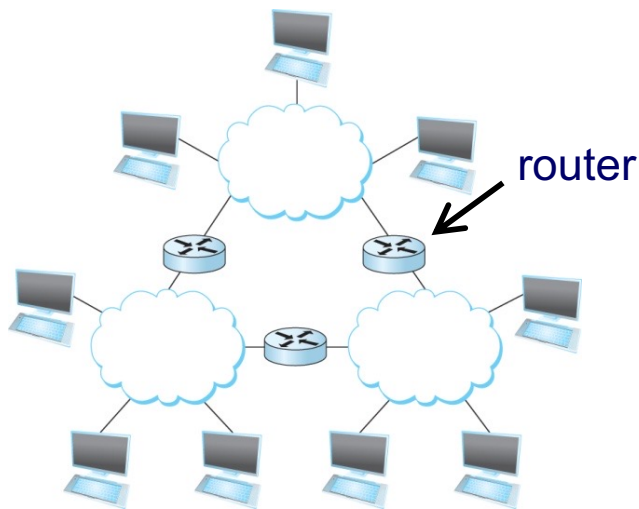
- Terminology (contd.)
 - **Packet, message** – block of data being communicated
 - **Switches** – nodes with multiple links that forward data/packets from one link to another
 - **Switched Network** – switches provide connectivity across a network by forwarding data between links
 - Circuit Switched – physically connect two links
 - Packet Switched – repeat a packet of data from one link to another
 - **Store-and-forward** – incoming packets are buffered (e.g., FIFO queue) and forwarded

Connectivity (cont.)

Switched Network



Interconnection of networks

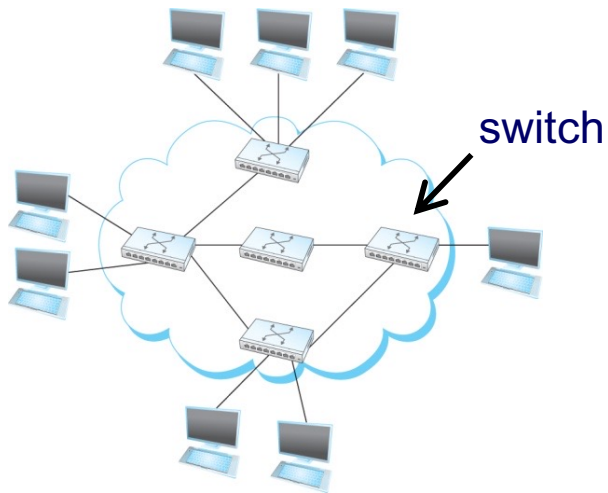


■ Terminology (contd.)

- **Cloud** – abstract view of a network
- **Hosts** – Computers/devices connected to the network
- **Router/gateway** – forwards data between networks
- **Routing** – forwarding of data over a path from one host to another
- **Host-to-host connectivity** – two hosts have a route between them
- **Address** – a number that describes the location of a host or router
- **Unicast/broadcast/multicast** – unicast is routing a message to one host, broadcast is forwarding a message to all hosts

Connectivity (cont.)

Switched Network - LAN



■ Terminology (contd.)

- **LAN (local area network)** – connects computers within a limited area, uses switches
- **WAN (wide area network)** – extends over a large geographic area, uses routers

Interconnection of networks - WAN

