EC 745 Telecommunication Networks

Instructor: Dr. Heba A. Shaban

Chapter 1 Communication Networks and Services

Computer Networks & Packet Switching

Computer Network Evolution Overview

- *1950s*: Telegraph technology adapted to computers
- *1960s*: Dumb terminals access shared host computer
  - SABRE airline reservation system
- *1970s*: Computers connect directly to each other
  - ARPANET packet switching network
  - TCP/IP internet protocols
  - Ethernet local area network
- *1980s & 1990s*: New applications and Internet growth
  - Commercialization of Internet
  - E-mail, file transfer, web, P2P, . . .
  - Internet traffic surpasses voice traffic

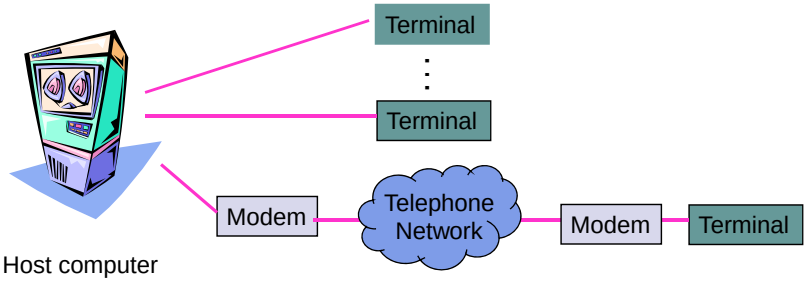
What is a protocol?

- Communications between computers requires very specific unambiguous rules
- A protocol is a set of rules that governs how two or more communicating parties are to interact
  - Internet Protocol (IP)
  - Transmission Control Protocol (TCP)
  - HyperText Transfer Protocol (HTTP)
  - Simple Mail Transfer Protocol (SMTP)

A familiar protocol

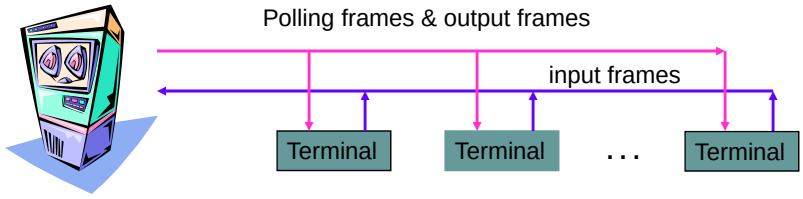
Terminal-Oriented Networks

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



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

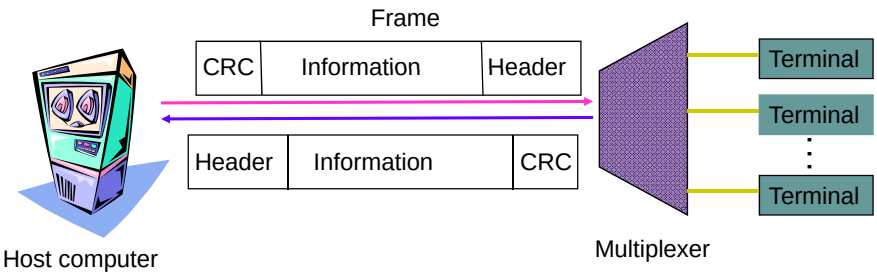


Host computer

Terminals at different locations in a city
Must avoid collisions on inbound 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

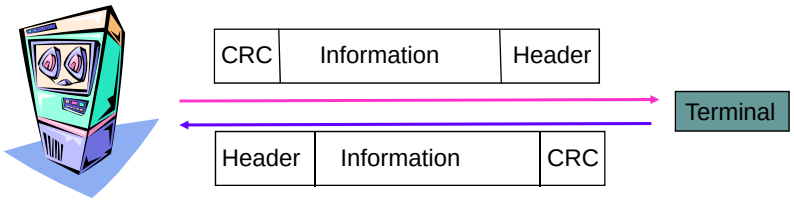


Host computer

Multiplexer

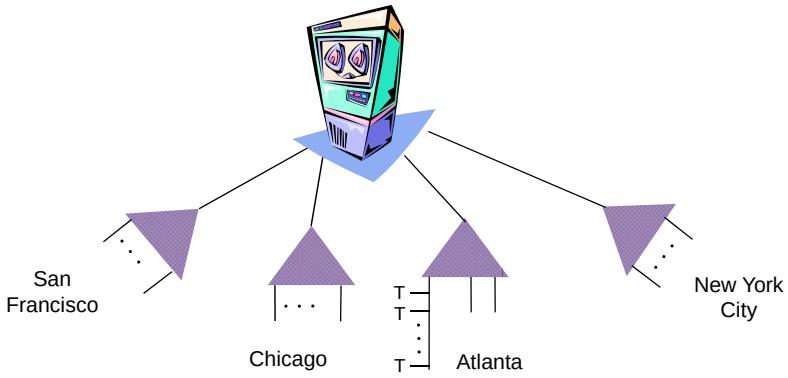
Error Control Protocol

- Communication lines introduced errors
- Error checking codes used on frames
  - "Cyclic Redundancy Check" (CRC) calculated based on frame header and information payload, and appended
  - Header also carries ACK/NAK control information
- Retransmission requested when errors detected



Tree Topology Networks

- National & international terminal-oriented networks
- Routing was very simple (to/from host)
- Each network typically handled a single application



Computer-to-Computer Networks

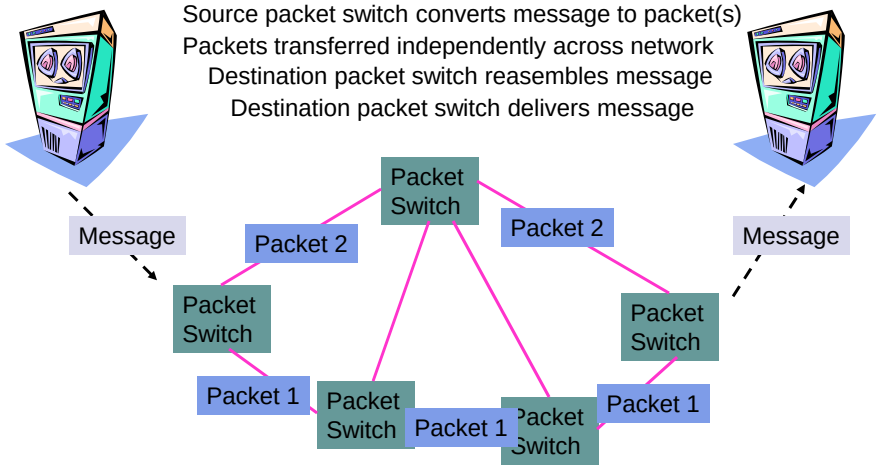
- As cost of computing dropped, terminal-oriented networks viewed as too inflexible and costly
- Need to develop flexible computer networks
  - Interconnect computers as required
  - Support many applications
- Application Examples
  - File transfer between arbitrary computers
  - Execution of a program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

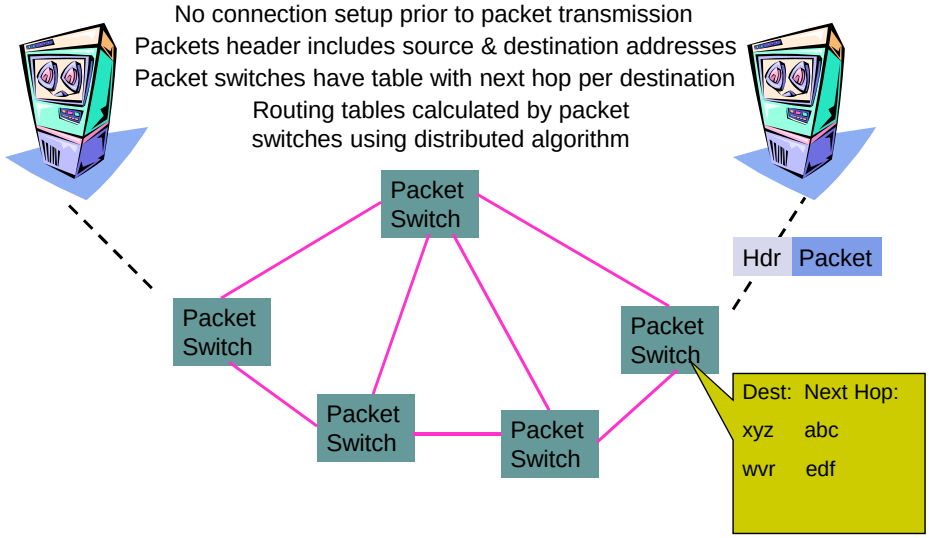
ARPANET Packet Switching

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

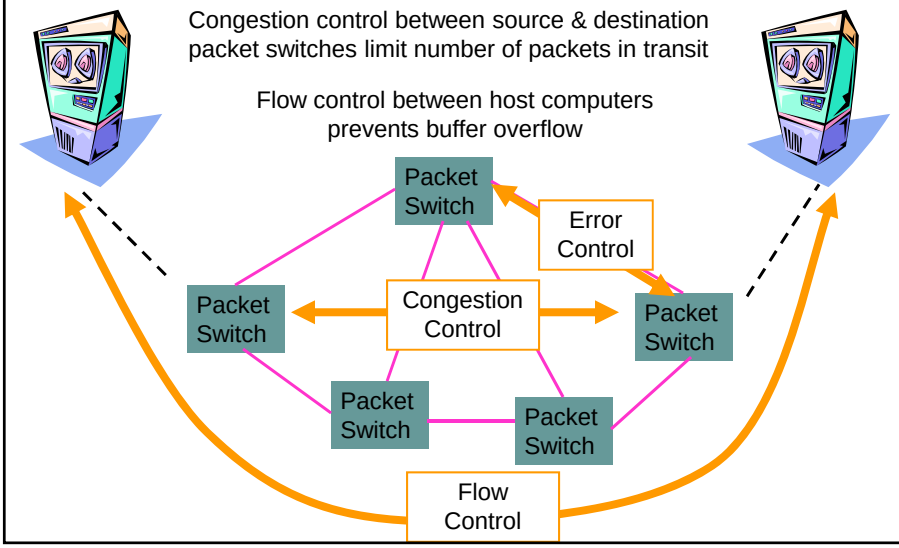


Other ARPANET Protocols

Error control between adjacent packet switches

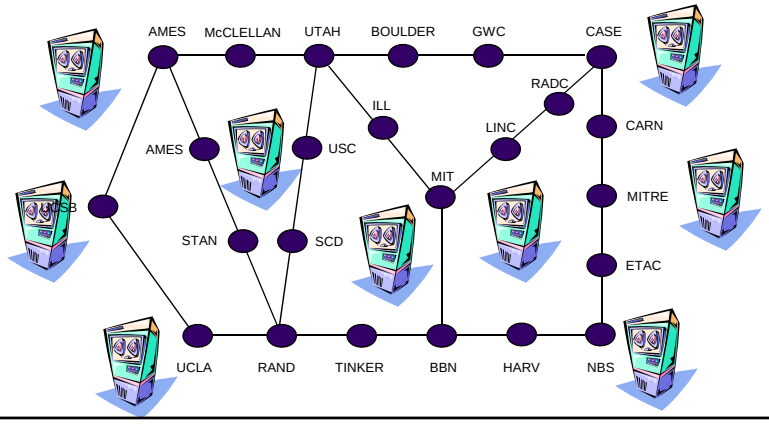
Congestion control between source & destination packet switches limit number of packets in transit

Flow control between host computers prevents buffer overflow



ARPANET Applications

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

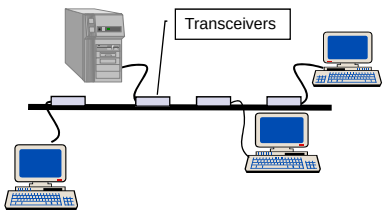


Ethernet Local Area Network

- In 1980s, affordable workstations available
- Need for low-cost, high-speed networks
  - To interconnect local workstations
  - To access local shared resources (printers, storage, servers)
- Low cost, high-speed communications with low error rate possible using coaxial cable
- Ethernet is the standard for high-speed wired access to computer networks

Ethernet Medium Access Control

- Network interface card (NIC) connects workstation to LAN
- Each NIC has globally unique address
- Frames are broadcast into coaxial cable
- NICs listen to medium for frames with their address
- Transmitting NICs listen for collisions with other stations, and abort and reschedule retransmissions



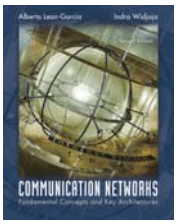
Elements of Computer Network Architecture

- *Digital transmission*
- Exchange of *frames* between adjacent equipment
  - Framing and error control
- *Medium access control* regulates sharing of broadcast medium.
- *Addresses* identify attachment to network or internet.
- Transfer of *packets* across a packet network
- Distributed calculation of *routing tables*

Elements of Computer Network Architecture

- *Congestion control* inside the network
- *Internetworking* across multiple networks using routers
- *Segmentation and reassembly* of messages into packets at the ingress to and egress from a network or internetwork
- *End-to-end transport protocols* for process-to-process communications
- *Applications* that build on the transfer of messages between computers.
- *Intelligence is at the edge of the network.*

Chapter 1
Communication Networks and Services



Future Network Architectures and Services

Trends in Network Evolution

- It's all about services
  - Building networks involves huge expenditures
  - Services that generate revenues drive the network architecture
- Current trends
  - Packet switching vs. circuit switching
  - Multimedia applications
  - More versatile signaling
  - End of trust
  - Many service providers and overlay networks
  - Networking *is* a business

Packet vs. Circuit Switching

- Architectures appear and disappear over time
  - Telegraph (message switching)
  - Telephone (circuit switching)
  - Internet (packet switching)
- Trend towards packet switching at the edge
  - IP enables rapid introduction of new applications
  - New cellular voice networks packet-based
  - Soon IP will support *real-time* voice and telephone network will gradually be replaced
  - However, large packet flows easier to manage by circuit-like methods

Optical Circuit Switching

- Optical signal transmission over fiber can carry huge volumes of information (Tbps)
- Optical signal processing very limited
  - Optical logic circuits bulky and costly
  - Optical packet switching will not happen soon
- Optical-to-Electronic conversion is expensive
  - Maximum electronic speeds << Tbps
  - Parallel electronic processing & high expense
- Thus trend towards optical circuit switching in the core

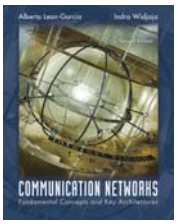
Multimedia Applications

- Trend towards digitization of *all* media
- Digital voice standard in cell phones
- Music cassettes replaced by CDs and MP3's
- Digital cameras replacing photography
- Video: digital storage and transmission
  - Analog VCR cassettes largely replaced by DVDs
  - Analog broadcast TV to be replaced by digital TV
  - VCR cameras/recorders to be replaced by digital video recorders and cameras
- High-quality network-based multimedia applications now feasible

End of Trust

- Security Attacks
  - Spam
  - Denial of Service attacks
  - Viruses
  - Impersonators
- Firewalls & Filtering
  - Control flow of traffic/data from Internet
- Protocols for privacy, integrity and authentication

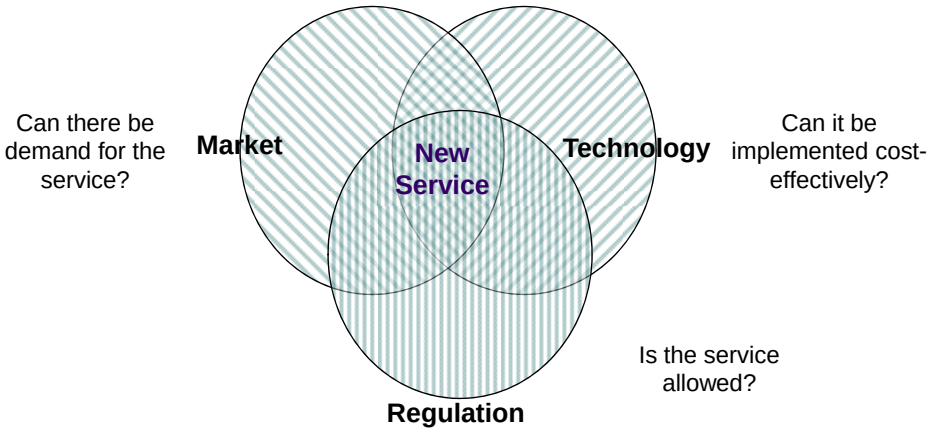
Chapter 1
Communication Networks and Services



Key Factors in Network Evolution

Success Factors for New Services

- Technology not only factor in success of a new service
- Three factors considered in new telecom services



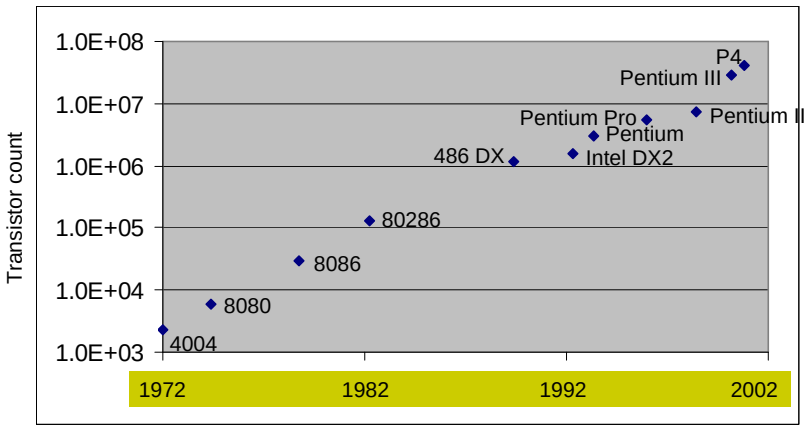
Transmission Technology

- Relentless improvement in transmission
- High-speed transmission in copper pairs
  - DSL Internet Access
- Higher call capacity in cellular networks
  - Lower cost cellular phone service
- Enormous capacity and reach in optical fiber
  - Plummeting cost for long distance telephone
- Faster and more information intensive applications

Processing Technology

- Relentless improvement in processing & storage
- Moore's Law: doubling of transistors per integrated circuit every two years
- RAM: larger tables, larger systems
- Digital signal processing: transmission, multiplexing, framing, error control, encryption
- Network processors: hardware for routing, switching, forwarding, and traffic management
- Microprocessors: higher layer protocols and applications
- Higher speeds and higher throughputs in network protocols and applications

Moore's Law



Software Technology

- Greater functionality & more complex systems
- TCP/IP in operating systems
- Java and virtual machines
- New application software
- Middleware to connect multiple applications
- Adaptive distributed systems

Market

- *The network effect*: usefulness of a service increases with size of community
  - Metcalfe's Law: usefulness is proportional to the square of the number of users
  - Phone, fax, email, ICQ, …
- *Economies of scale*: per-user cost drops with increased volume
  - Cell phones, PDAs, PCs
  - Efficiencies from multiplexing
- *S-curve*: growth of new service has S-shaped curve, challenge is to reach the critical mass

Regulation & Competition

- Telegraph & Telephone originally monopolies
  - Extremely high cost of infrastructure
  - Profitable, predictable, slow to innovate
- Competition feasible with technology advances
  - Long distance cost plummeted with optical tech
  - Alternative local access through cable, wireless
  - Radio spectrum: auctioned vs. unlicensed
- Basic connectivity vs. application provider
  - Tussle for the revenue-generating parts

Standards

- New technologies very costly and risky
- Standards allow players to share risk and benefits of a new market
  - Reduced cost of entry
  - Interoperability and network effect
  - Compete on innovation
  - Completing the value chain
    - Chips, systems, equipment vendors, service providers
- Example
  - 802.11 wireless LAN products

Standards Bodies

- Internet Engineering Task Force
  - Internet standards development
  - Request for Comments (RFCs): www.ietf.org
- International Telecommunications Union
  - International telecom standards
- IEEE 802 Committee
  - Local area and metropolitan area network standards
- Industry Organizations
  - MPLS Forum, WiFi Alliance, World Wide Web Consortium