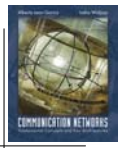
Chapter 1 Communication Networks and Services

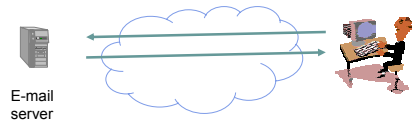


Network Architecture and Services
Telephone Networks and Circuit Switching
Computer Networks & Packet Switching

Communication Services & Applications

- A communication service enables the exchange of information between users at different locations.
- Communication services & applications are everywhere.

E-mail



Exchange of text messages via servers

Communication Services & Applications

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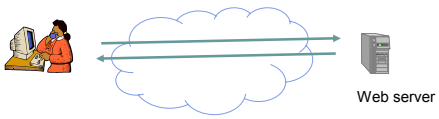
Web Browsing



Retrieval of information from web servers

Communication Services & Applications

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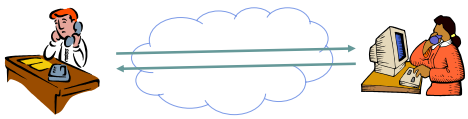
Telephone



Real-time bidirectional voice exchange

Services & Applications

- Service: Basic information transfer capability
  - Internet transfer of individual block of information
  - Internet reliable transfer of a stream of bytes
  - Real-time transfer of a voice signal
- Applications build on communication services
  - E-mail & web build on reliable stream service
  - Fax and modems build on basic telephone service
- New applications build on multiple networks
  - SMS builds on Internet reliable stream service and cellular telephone text messaging

What is a communication network?

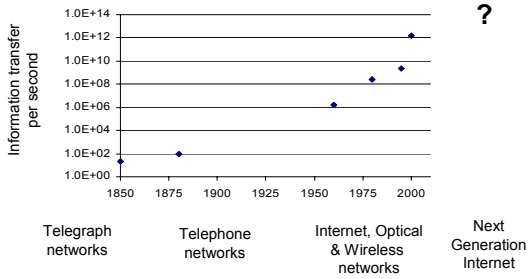
- The equipment (hardware & software) and facilities that provide the basic communication service
- Virtually invisible to the user; Usually represented by a cloud
- Equipment
  - Routers, servers, switches, multiplexers, hubs, modems, …
- Facilities
  - Copper wires, coaxial cables, optical fiber
  - Ducts, conduits, telephone poles …

How are communication networks designed and operated?

Communication Network Architecture

- *Network architecture:* the plan that specifies how the network is built and operated
- Architecture is driven by the network services
- Overall communication process is complex
- Network architecture partitions overall communication process into separate functional areas called *layers*
- Evolution of three network architectures: telegraph, telephone, and computer networks

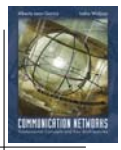
Network Architecture Evolution



Network Architecture Evolution

- Telegraph Networks
  - Message switching & digital transmission
- Telephone Networks
  - Circuit Switching
  - Analog transmission → digital transmission
  - Mobile communications
- Internet
  - Packet switching & computer applications
- Next-Generation Internet
  - Multiservice packet switching network

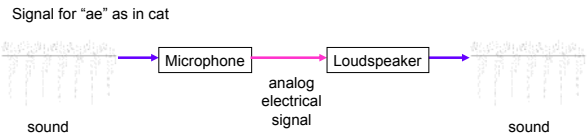
Chapter 1
Communication Networks and Services



Telephone Networks and Circuit Switching

Bell's Telephone

- Alexander Graham Bell (1875) working on harmonic telegraph to multiplex telegraph signals
- Discovered voice signals can be transmitted directly
  - Microphone converts voice pressure variation (sound) into *analogous* electrical signal
  - Loudspeaker converts electrical signal back into sound
- Telephone patent granted in 1876
- Bell Telephone Company founded in 1877

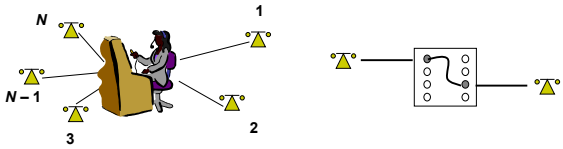


Elements of Telephone Network Architecture

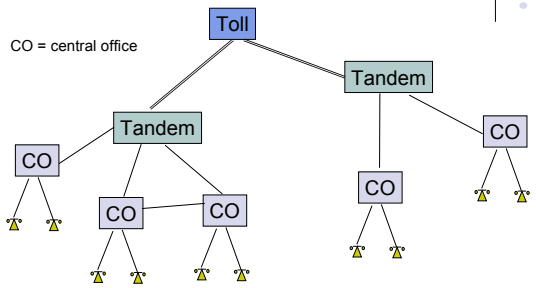
- Digital transmission & switching
  - Digital voice; Time Division Multiplexing
- Circuit switching
  - User signals for call setup and tear-down
  - Route selected during connection setup
  - End-to-end connection across network
  - Signaling coordinates connection setup
- Hierarchical Network
  - Decimal numbering system
  - Hierarchical structure; simplified routing; scalability
- Signaling Network
  - Intelligence inside the network

Circuit Switching

- Patchcord panel switch invented in 1877
- Operators connect users on demand
  - Establish *circuit* to allow electrical current to flow from inlet to outlet
- Only *N* connections required to central office



Hierarchical Network Structure

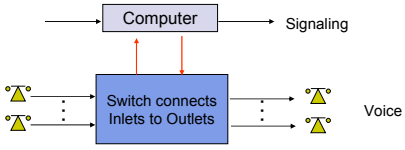


Telephone subscribers connected to local CO (central office)

Tandem & Toll switches connect CO's

Connection Control

- A computer controls connection in telephone switch
- Computers exchange *signaling messages* to:
  - Coordinate set up of telephone connections
  - To implement new services such as caller ID, voice mail, . . .
  - To enable *mobility and roaming in* cellular networks
- "Intelligence" inside the network
- A separate *signaling network* is required

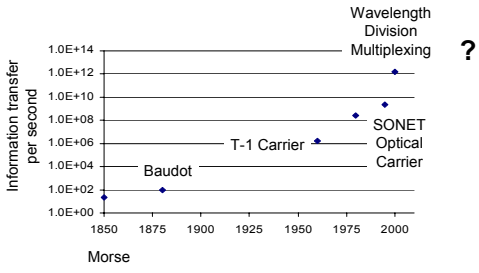


Digitization of Telephone Network

- Pulse Code Modulation digital voice signal
  - Voice gives 8 bits/sample x 8000 samples/sec = 64×10^3 bps
- Time Division Multiplexing for digital voice
  - T-1 multiplexing (1961): 24 voice signals = 1.544×10^6 bps
- Digital Switching (1980s)
  - Switch TDM signals without conversion to analog form
- Digital Cellular Telephony (1990s)
- Optical Digital Transmission (1990s)
  - One OC-192 optical signal = 10×10^9 bps
  - One optical fiber carries 160 OC-192 signals = 1.6×10^{12} bps!

All digital transmission, switching, and control

Digital Transmission Evolution



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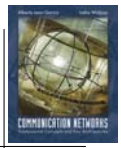


Computer Networks & Packet Switching

Computer Network Evolution

- *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

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*

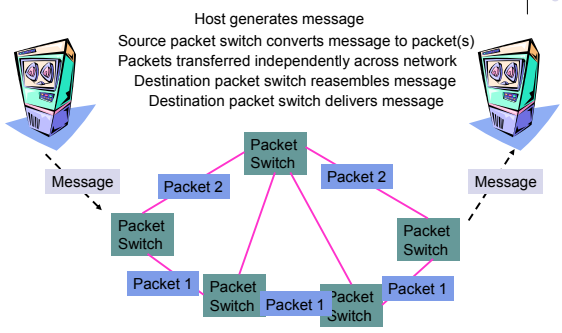
Elements of Computer Network Architecture

- *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.*

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

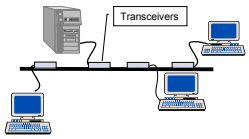


Ethernet Local Area Network

- 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

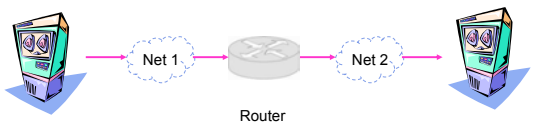


The Internet

- Different network types emerged for data transfer between computers
- ARPA also explored packet switching using satellite and packet radio networks
- Each network has its protocols and is possibly built on different technologies
- *Internetworking protocols* required to enable communications between computers attached to *different* networks
- ***Internet***: a network of networks

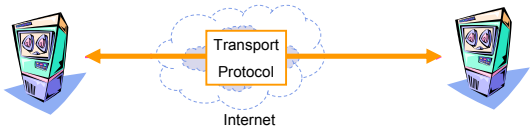
Internet Protocol (IP)

- *Routers (gateways)* interconnect different networks
- Host computers prepare IP packets and transmit them over their attached network
- Routers forward IP packets across networks
- *Best-effort* IP transfer service, no retransmission



Transport Protocols

- Host computers run two transport protocols on top of IP to enable process-to-process communications
- *User Datagram Protocol* (UDP) enables best-effort transfer of individual block of information
- *Transmission Control Protocol* (TCP) enables reliable transfer of a stream of bytes



Internet Applications

- All Internet applications run on TCP or UDP
- TCP: HTTP (web); SMTP (e-mail); FTP (file transfer; telnet (remote terminal)
- UDP: DNS, RTP (voice & multimedia)
- TCP & UDP incorporated into computer operating systems
- Any application designed to operate over TCP or UDP will run over the Internet

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

Multimedia Applications

- Trend towards digitization of *all* media
- Digital voice standard in cell phones
- 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

More Versatile Signaling

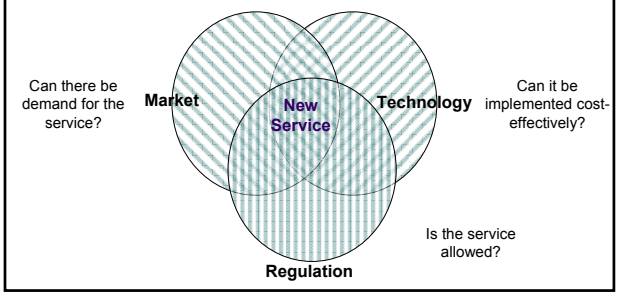
- Signaling inside the network
  - Connectionless packet switching keeps network simple & avoids large scale signaling complexity
  - Large packet flows easier to manage using circuit-like methods that require signaling
  - Optical paths also require signaling
  - Generalized signaling protocols being developed
- End-to-End Signaling
  - Session-oriented applications require signaling between the endpoints (not inside the network)
  - Session Initiation Protocol taking off

Operation, Administration, and Maintenance (OAM)

- Communication like transportation networks
  - Traffic flows need to be monitored and controlled
  - Tolls have to be collected
  - Roads have to be maintained
  - Need to forecast traffic and plan network growth
- Highly-developed in telephone network
  - Entire organizations address OAM & Billing
  - Becoming automated for flexibility & reduced cost
- Under development for IP networks

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