

ECE 683-001 Fall 2005 Computer Network Design and Analysis Lecture 1

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Sources:

- **Warriors of the Net**
- **Communication Networks** 2nd Edition Chapter 1
by Alberto Leon-Garcia and Indra Widjaja



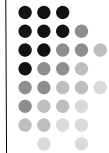
Network Architecture and Services
Telegraph Networks & Message Switching
Telephone Networks and Circuit Switching
Computer Networks & Packet Switching
Future Network Architectures and Services
Key Factors in Network Evolution



Lecture 1 Communication Networks and Services



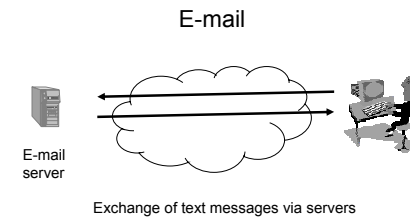
*Network Architecture and
Services*



Communication Services & Applications



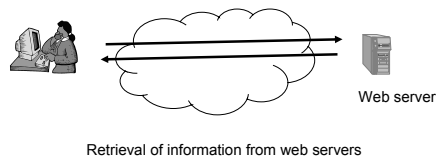
- A communication service enables the exchange of information between users at different locations.
- Communication services & applications are everywhere.



Communication Services & Applications

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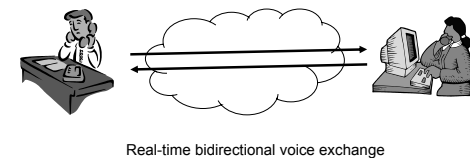
Web Browsing



Communication Services & Applications

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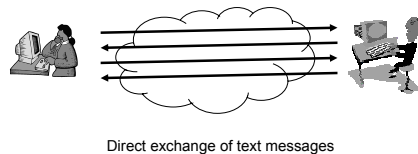
Telephone



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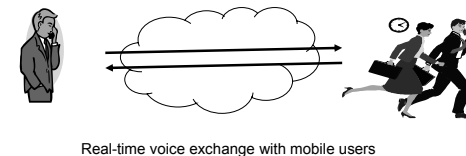
Instant Messaging



Communication Services & Applications

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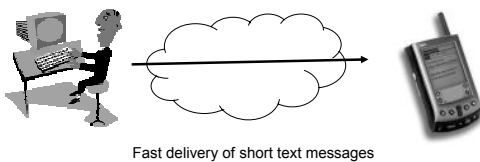
Cell phone



Communication Services & Applications

- A communication service enables the exchange of information between users at different locations.
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Short Message Service



Many other examples!

- Peer-to-peer applications
 - Napster, Gnutella, Kazaa file exchange
 - Searching for ExtraTerrestrial Intelligence (SETI)
- Audio & video streaming
- Network games
- On-line purchasing
- Text messaging in PDAs, cell phones (SMS)
- Voice-over-Internet

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?

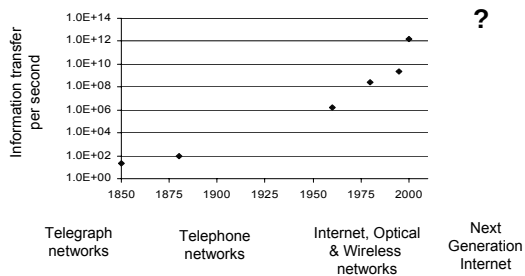
Communication Network Architecture



- *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*

Next we will trace evolution of three network architectures: telegraph, telephone, and computer networks

Network Architecture Evolution



Voice Networks



Type	# of voice channels	Data Rate, Mbps	Combinations
T1	24	1.544	
T1C	48	3.152	2 T1
T2	96	6.312	4 T1 or 2 T1C
T3	672	44.736	28 T1, 14 T1C, or 7 T2
T4	4032	274.176	168 T1, 84 T1C, or 42 T2

≈ 40 year old technologies

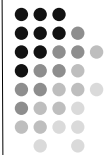
Network Architecture Evolution



- 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

Lecture 1 Communication Networks and Services

Telegraph Networks & Message Switching



Telegraphs & Long-Distance Communications

Approaches to long-distance communications

- Courier: physical transport of the message
 - Messenger pigeons, pony express, FedEx
- Telegraph: message is transmitted across a network using signals
 - Drums, beacons, mirrors, smoke, flags, semaphores...
 - Electricity, light
- Telegraph delivers message much sooner



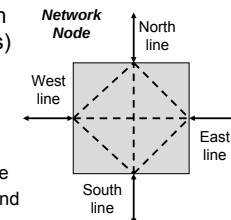
Optical (Visual) Telegraph

- Claude Chappe invented optical telegraph in the 1790's
- Semaphore mimicked a person with outstretched arms with flags in each hand
- Different angle combinations of arms & hands generated hundreds of possible signals
- Code for enciphering messages kept secret
- Signal could propagate 800 km in 3 minutes!



Message Switching

- Network nodes were created where several optical telegraph lines met (Paris and other sites)
- *Store-and-Forward* Operation:
 - Messages arriving on each line were decoded
 - Next-hop in **route** determined by destination **address** of a message
 - Each message was carried by hand to next line, and stored until operator became available for next transmission



Electric Telegraph



- William Sturgeon Electro-magnet (1825)
 - Electric current in a wire wrapped around a piece of iron generates a magnetic force
- Joseph Henry (1830)
 - Current over 1 mile of wire to ring a bell
- Samuel Morse (1835)
 - Pulses of current deflect electromagnet to generate dots & dashes
 - Experimental telegraph line over 40 miles (1840)
- Signal propagates at the speed of light!!!
 - Approximately 2×10^8 meters/second in cable

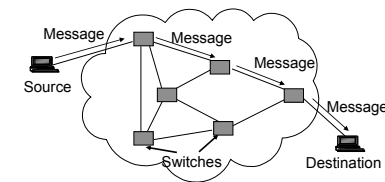
Digital Communications

- Morse code converts text message into sequence of dots and dashes
- Use transmission system designed to convey dots and dashes

	Morse Code		Morse Code		Morse Code		Morse Code
A	· —	J	· — — — —	S	· · ·	2	· · · — — — —
B	— · · ·	K	— · — — —	T	—	3	· · · — — — —
C	— · — — ·	L	· — · ·	U	· · — —	4	· · · · — — —
D	— · ·	M	— — — —	V	· · · — —	5	· · · · ·
E	·	N	— · —	W	· — — —	6	— · · · ·
F	· · — —	O	— — — —	X	— · · — —	7	— — — · ·
G	— — — ·	P	· — — — ·	Y	— · — — —	8	— — — — ·
H	· · · ·	Q	— — — — ·	Z	— — — · ·	9	— — — — ·
I	· ·	R	· — — ·	1	· — — — —	0	— — — — —

Electric Telegraph Networks

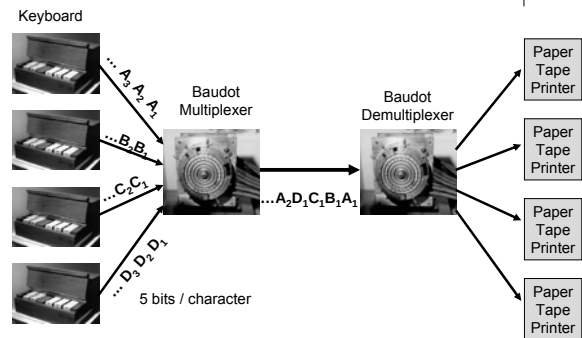
- Electric telegraph networks exploded
 - Message switching & Store-and-Forward operation
 - Key elements: Addressing, Routing, Forwarding
- Optical telegraph networks disappeared



Baudot Telegraph Multiplexer

- Operator 25-30 words/minute
 - but a wire can carry much more
- Baudot multiplexer: Combine 4 signals in 1 wire
 - Binary block code (ancestor of ASCII code)
 - A character represented by 5 bits
 - Time division *multiplexing*
 - Binary codes for characters are interleaved
 - *Framing* is required to recover characters from the binary sequence in the multiplexed signal
 - *Keyboard* converts characters to bits

Baudot Telegraph Multiplexer



Elements of Telegraph Network Architecture

- Digital transmission
 - Text messages converted into symbols (dots/dashes, zeros/ones)
 - Transmission system designed to convey symbols
- Multiplexing
 - *Framing* needed to recover text characters
- Message Switching
 - Messages contain source & destination *addresses*
 - *Store-and-Forward*: Messages forwarded hop-by-hop across network
 - *Routing* according to destination address

Lecture 1 Communication Networks and Services

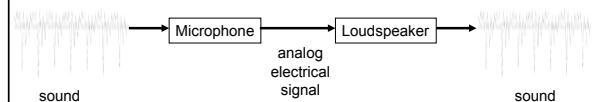


Telephone Networks and Circuit Switching

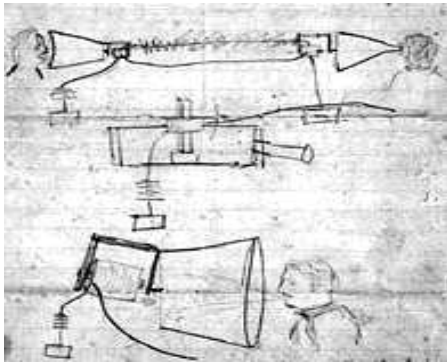
Bell's Telephone

- 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

Signal for "ae" as in cat

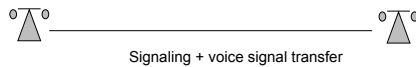


Bell's Sketch of Telephone



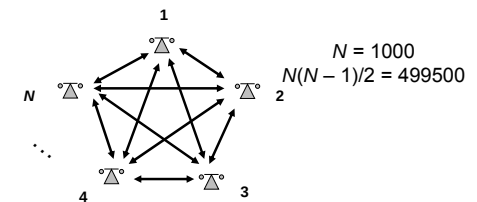
Signaling

- Signaling required to establish a call
 - Flashing light and ringing devices to alert the called party of incoming call
 - Called party information to operator to establish calls

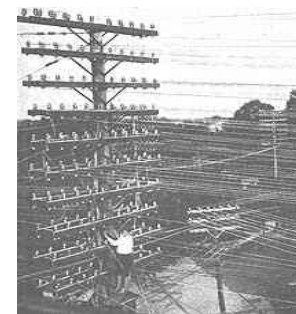


The N^2 Problem

- For N users to be fully connected *directly*
- Requires $N(N - 1)/2$ connections
- Requires too much space for cables
- Inefficient & costly since connections not always on

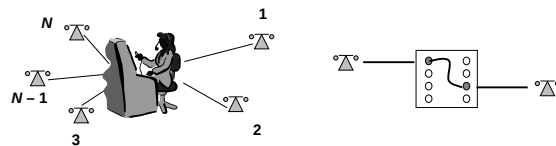


Telephone Pole Congestion



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

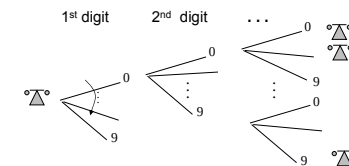


Manual Switching

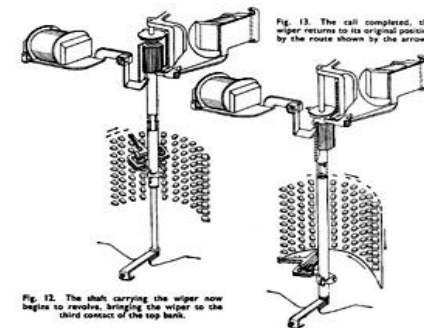


Strowger Switch

- Human operators intelligent & flexible
 - But expensive and not always discreet
- Strowger invented automated switch in 1888
 - Each current pulse advances wiper by 1 position
 - User dialing controls connection setup
- Decimal telephone numbering system
- Hierarchical network structure simplifies routing
 - Area code, exchange (CO), station number

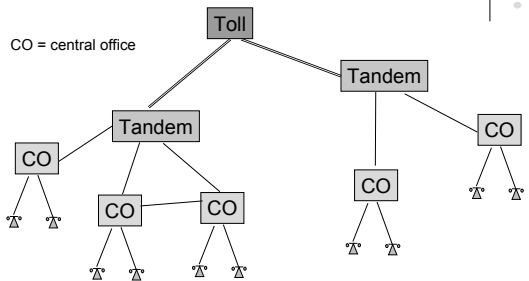


Strowger Switch



Hierarchical Network Structure

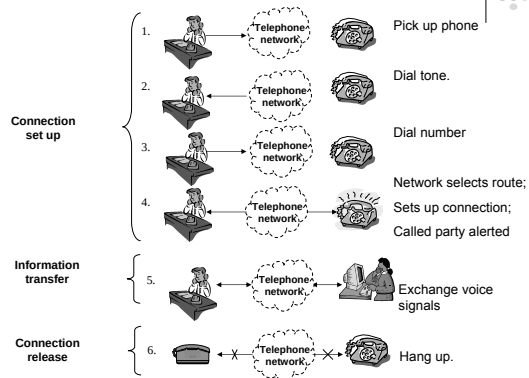
CO = central office



Telephone subscribers connected to local CO (central office)

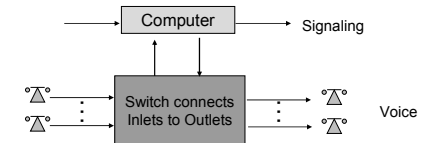
Tandem & Toll switches connect CO's

Three Phases of a Connection



Computer 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

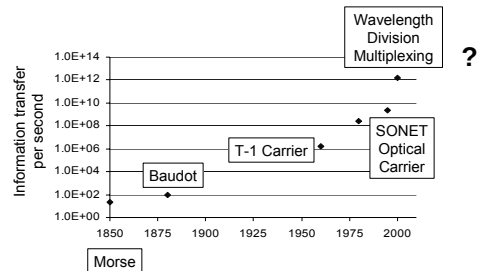


Digitization of Telephone Network

- 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



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

Lecture 1 Communication Networks and Services



Computer Networks & Packet Switching

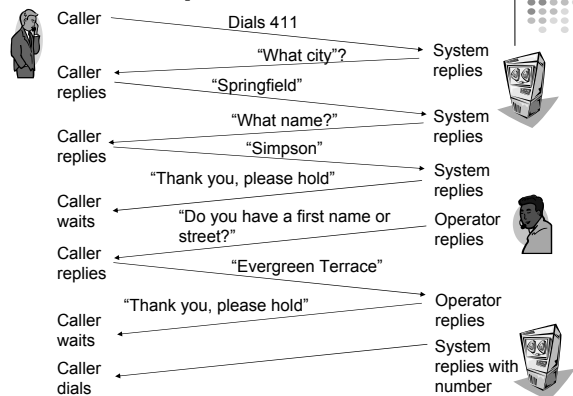
Computer Network Evolution Overview

- 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?

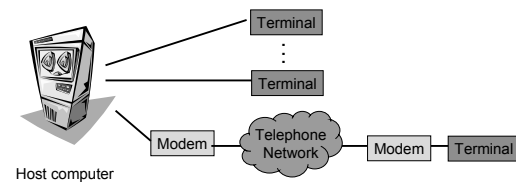
- Communications between computers requires very specific unambiguous rules
- A protocol is a set of rules that governs how two or more communicating parties are to interact
 - Internet Protocol (IP)
 - Transmission Control Protocol (TCP)
 - HyperText Transfer Protocol (HTTP)
 - Simple Mail Transfer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

A familiar protocol



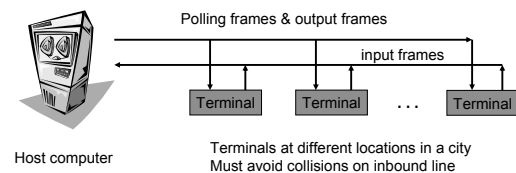
Terminal-Oriented Networks

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



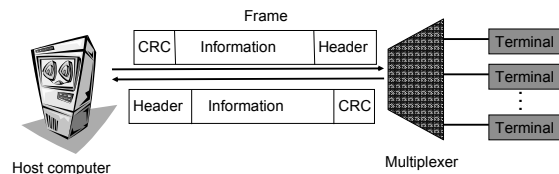
Medium Access Control

- 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



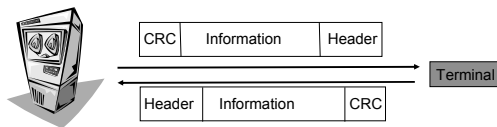
Statistical Multiplexing

- 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



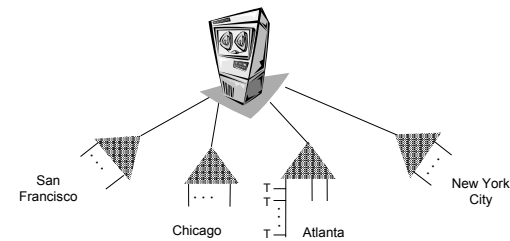
Error Control Protocol

- Communication lines introduced errors
- Error checking codes used on frames
 - "Cyclic Redundancy Check" (CRC) 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



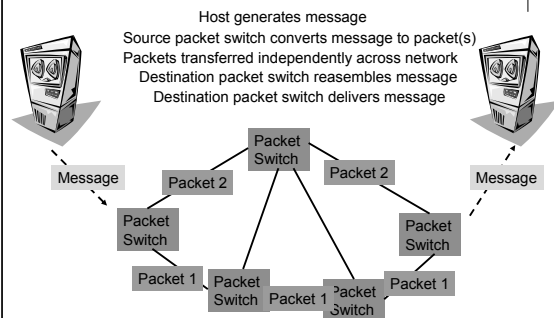
Computer-to-Computer Networks

- 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

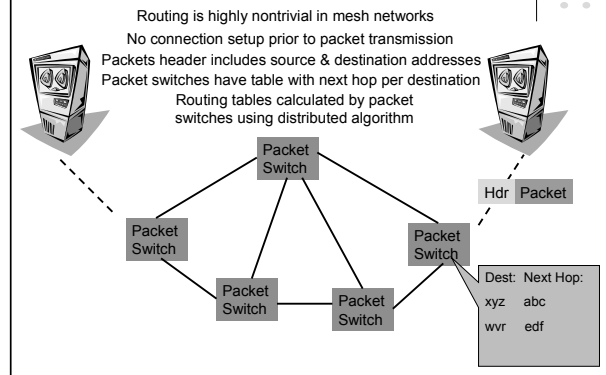
Packet Switching

- 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

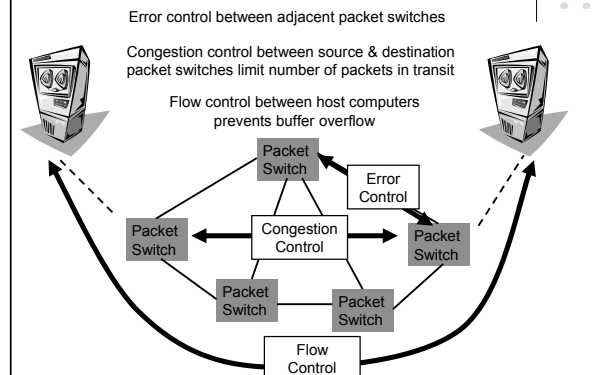
ARPANET Packet Switching



ARPANET Routing

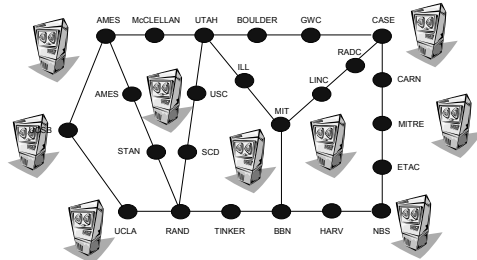


Other ARPANET Protocols



ARPANET Applications

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

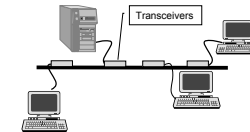


Ethernet Local Area Network

- 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

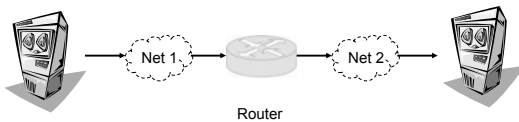


The Internet

- 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

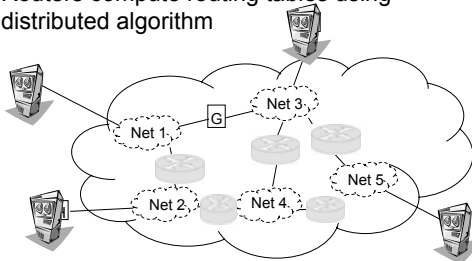
Internet Protocol (IP)

- *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



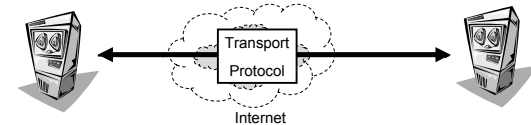
Addressing & Routing

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



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



Names and IP Addresses

- Routing is done based on 32-bit IP addresses
- Dotted-decimal notation
 - 128.235.204.127
- Hosts are also identified by name
 - Easier to remember
 - Hierarchical name structure
 - bloch.njit.edu (alias afs5.njit.edu)
- Domain Name System (DNS) provided conversion between names and addresses

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!!!

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

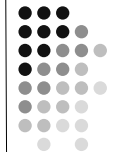


- *Congestion control* inside the network
- *Internetworking* across multiple networks using routers
- *Segmentation and reassembly* of messages into packets at the ingress to and egress from a network or internetwork
- *End-to-end transport protocols* for process-to-process communications
- *Applications*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

Lecture 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 $\ll$ 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

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

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

Servers & Services



- Many Internet applications involve interaction between client and server computers
 - Client and servers are at the edge of the Internet
 - SMTP, HTTP, DNS, ...
- Enhanced services in telephone network also involve processing from servers
 - Caller ID, voice mail, mobility, roaming, ...
 - These servers are inside the telephone network
 - Internet-based servers at the edge can provide same functionality
- In future, multiple service providers can coexist and serve the same customers

P2P and Overlay Networks



- Client resources under-utilized in client-server
- Peer-to-Peer applications enable sharing
 - Napster, Gnutella, Kazaa
 - Processing & storage (SETI@home)
 - Information & files (MP3s)
 - Creation of virtual distributed servers
- P2P creates transient overlay networks
 - Users (computers) currently online connect directly to each other to allow sharing of their resources
 - Huge traffic volumes a challenge to network management
 - Huge opportunity for new businesses

Operations, Administration, Maintenance, and Billing

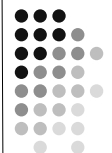


- Communication like transportation networks
 - Traffic flows need to be monitored and controlled
 - Tolls have to be collected
 - Roads have to be maintained
 - Need to forecast traffic and plan network growth
- Highly-developed in telephone network
 - Entire organizations address OAM & Billing
 - Becoming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

Lecture 1 Communication Networks and Services



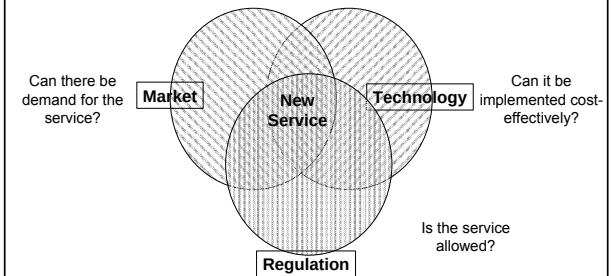
Key Factors in Network Evolution



Success Factors for New Services



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



Transmission Technology

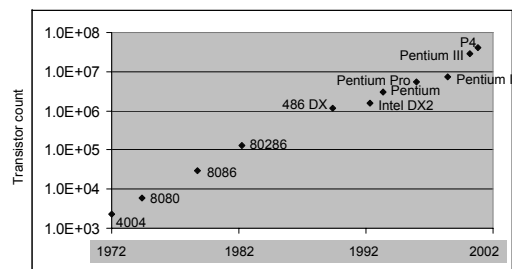


- Relentless improvement in transmission
- High-speed transmission in copper pairs
 - DSL Internet Access
- Higher call capacity in cellular networks
 - Lower cost cellular phone service
- Enormous capacity and reach in optical fiber
 - Plummeting cost for long distance telephone
- Faster and more information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



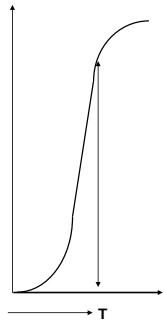
Software Technology

- 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

The S Curve



Service Penetration & Network Effect

- Telephone: T=30 years
 - city-wide & inter-city links
- Automobile: T=30 years
 - roads
- Others
 - Fax
 - Cellular & cordless phones
 - Internet & WWW
 - Napster and P2P



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

