



*Department of
Information Sciences and Telecommunications*



Computer Networks – TELCOM 2310

Lecture 1
Introduction

Prof. Taieb Znati

Lecture Outline



- ✘ **Administrative Issues**
- ✘ Introduction to computer networks and networking

Instructor



✘ Instructor

- ✘ Prof. Taieb Znati
 - ✦ 6401 Sennott Square, Computer Science Department
 - ✦ znati@cs.pitt.edu,
 - ✦ (412) 624-8417
- ✘ Office Hours: MW – 10:30-12:00 a.m. and by appointment

✘ Teaching Assistant

- ✘ Carlos Caicedo
 - ✦ SIS 838A (Inside room SIS 835)
 - ✦ (412) 624-9490
 - ✦ cec15@pitt.edu
- ✘ Office Hours:
 - ✦ Tuesday: 3:30 p.m. – 5:30 p.m.
 - ✦ Thursday: 11:00 a.m. – 1:00 p.m.
 - ✦ Also by appointment

Course objectives



✘ The course provides an overview of commonly used techniques in computer communication networks

- ✘ Whenever possible and useful, a quantitative approach is used to discuss the topics

✘ The good understanding of fundamental concepts and ideas, underlying design and implementation of computer networks, is the main course objective

Course Goals



- ✘ Gain deep understanding of the principles and practice of data networking
 - ✘ Flow and congestion control, routing, end-to-end transport protocols, naming, addressing,
- ✘ Learn how to write network applications
 - ✘ Sockets and network APIs
 - ✘ Process interaction paradigms
 - ⊕ Client/Server model?
 - ⊕ P2P and overlay networks
- ✘ Get some understanding about network internals
 - ✘ Through hands on experience and software project development

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Course Format



- ✘ Lectures
 - ✘ Cover the “principles and practice”
 - ✘ Complete readings before lecture
- ✘ Homework assignments
 - ✘ Loosely tied to lecture materials
 - ✘ To complement lectures and teach networking concepts/tools
- ✘ Programming project
 - ✘ Implement and analyze network protocols
- ✘ Two intermediate exams and a final exam
 - ✘ Non cumulative
 - ⊕ Cover each part of the course material

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Administrative Stuff



- ✘ Watch the course web page
 - ✘ <http://www.cs.pitt.edu/~znati/telcom2310.html>
 - ✘ Handouts, readings, ..
 - ✘ Homework assignments
 - ✘ Postings

- ✘ Read Bulletin Board
 - ✘ Post your questions, concerns, ...
 - ✘ Participation in the discussion is highly recommended

Grading Policy



- ✘ Final grade will be based on the following:
 - ✘ 20% Homework and programming assignments
 - ✘ 15% Exam I
 - ✘ 15% Exam II
 - ✘ 25% Project
 - ✘ 25% Final exam

- ✘ You **MUST** demonstrate competence in homework assignments, project and tests to pass the course
 - ✘ Class participation is highly recommended

Policy on Collaboration



- ✘ Working together is expected and highly recommended
 - ✘ Discuss course material in general terms
 - ✘ Work together on program debugging, ..

- ✘ Final submission *must* be your own work
 - ✘ Homework assignments, exams, and final

- ✘ Project -- Teams of two students
 - ✘ Collaboration, group project skills
 - ✘ Both students should understand and be able to demonstrate the entire project

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Late Work and Re-grading Policies



- ✘ Late work will receive a 15% penalty per day
 - ✘ No assignment can be more than 2 days late
 - ✘ Only exception is documented illness and family emergencies

- ✘ Requests for re-grading must be discussed with the TA first
 - ✘ Request must be submitted to the TA within 2 weeks after homework is returned.
 - ✘ In case of continued disagreement, instructor must be informed

- ✘ Ample time for homework and project assignments
 - ✘ Homework and programming assignments: ~1-2 weeks
 - ✘ Project: at least 6 weeks before deadline
 - ✘ You may end up discovering that a 6 week project cannot be completed in a week
 - ⚡ START EARLY

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Textbooks and Recommended Readings



- ✘ **Behrouz A. Forouzan: *TCP/IP Protocol Suite*, 3rd Edition, Addison-Wesley, 2006.**
- ✘ **James F. Kurose, Keith W. Ross: *Computer Networking: A Top-Down Approach Featuring the Internet*, Addison Wesley 3rd Edition;**
- ✘ **John D. Spragins et al.: *Telecommunications: Protocols and Design*, Addison-Wesley 1991.**
- ✘ **Douglas E. Comer, David L. Stevens: *Internetworking with TCP/IP*, Prentice Hall, 1992**
- ✘ **W. Richard Stevens, Gary R. Wright: *TCP/IP Illustrated*, Vol. 1, 2 and 3, Addison-Wesley 1994**

Lecture Outline



- ✘ Administrative Issues

- ✘ Introduction to Computer Networks and Networking
 - ✘ Simple Communication Model

Communication models

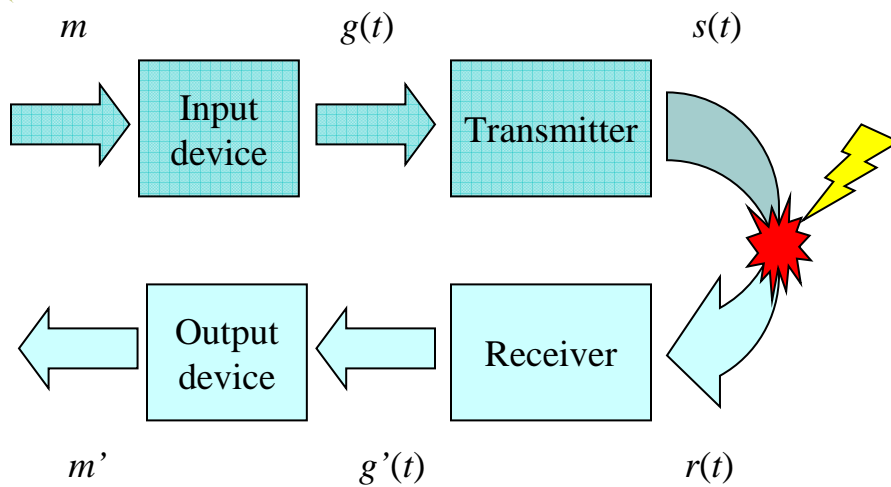
- ✘ The fundamental purpose of data communication is to exchange information between two entities
 - ✘ Information is represented as data and carries meaning currently assigned (depending on a context) to those data
 - ⊕ Data represents facts, concepts, or instructions in a formalized manner suitable for communication, or processing by human or machines

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Simple Communication Model



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Simple Communication Model



- ✘ m : original information message created by sending entity
- ✘ $g(t)$: time varying signal, not suitable for transmission
- ✘ $s(t)$: signal obtained by converting $g(t)$ into a form that matches the characteristics of the transmission medium
- ✘ $r(t)$: received signal which may be different from $s(t)$
- ✘ $g'(t)$: signal obtained by converting $r(t)$ into a form suitable for output
- ✘ m' : estimated message produced by destination entity

Simple Communication Model



- ✘ Although simple, the model highlights several communication tasks:
 - ✘ Interfacing,
 - ✘ Signal generation,
 - ✘ Synchronization,
 - ✘ Error detection and correction,
 - ✘ Flow control,
 - ✘ Framing, message formatting

Lecture Outline



- ✘ Administrative Issues
- ✘ Introduction to Computer Networks and Networking
 - ✘ Computer Networks and Internetworking

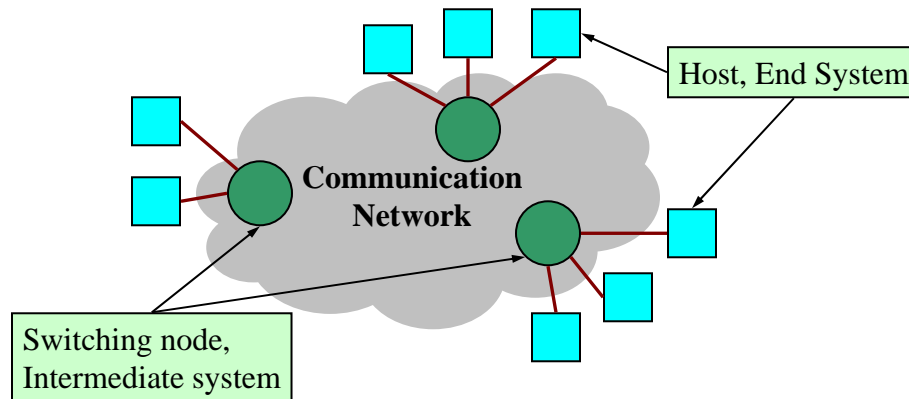
Data Communication Networks



- ✘ Point-to-point communication is the simplest form of data communication
 - ✘ Not practical to provide a dedicated wire between each pair of devices
- ✘ Communication networks provide efficient means for data communication between multiple devices

Communications Networks

- ✘ Network is a collection of nodes capable of transporting data between pairs of attached stations.



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What is a Computer Network?

- ✘ Software and hardware infrastructure:
 - ✘ It allows access to different types of resources (original purpose)
 - ✚ Computing resources, input/output devices, files, databases...
 - ✘ It provides a medium through which geographically dispersed users communicated (e.g. e-mail, chatting, teleconferencing)
 - ✘ An electronic village
 - ✘ An information highway, national information infrastructure
 - ✘ Cyberspace – “A consensual [environment] experienced daily by billions of operators, in every nation, ...”

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Networking Objective



- ✘ Enable communication between applications on different computers
 - ✘ Web services
 - ✘ Peer to Peer applications
 - ✘ Multimedia communications
- ✘ Must understand application needs/demands
 - Traffic data rate
 - ✘ Traffic pattern (bursty or constant bit rate)
 - ✘ Traffic target (multipoint or single destination, mobile or fixed)
 - ✘ Delay sensitivity
 - ✘ Loss sensitivity

Networks Functionalities



- ✘ Link
- ✘ Multiplexing
- ✘ Routing
- ✘ Addressing/naming (locating peers)
- ✘ Reliability
- ✘ Flow control
- ✘ Fragmentation
- ✘ Etc....

Network Design Challenges



- ✘ Geographic scope
 - ✘ The Internet vs. Andrew
- ✘ Scale
 - ✘ The Internet vs. your home network
- ✘ Application types
 - ✘ Email vs. video conferencing
- ✘ Trust and Administration
 - ✘ Corporate network – one network “provider”
 - ✘ Internet – 17,000 network providers

Network Design Challenges (II)



- ✘ Many differences between networks
 - ✘ Address formats
 - ✘ Performance – bandwidth/latency
 - ✘ Packet size
 - ✘ Loss rate/pattern/handling
 - ✘ Routing
- ✘ How to translate between various network technologies?

Classes of Networks



- ✘ Networks are usually defined according to
 - ✘ Geographical extent
 - ✘ Purpose
 - ✘ Implementation

Classes of Networks



- ✘ Based on geographical extent, the following classes of networks are identified:
 - ✘ Local Area Networks (LANs)
 - ✘ Metropolitan Area Networks (MANs)
 - ✘ Wide Area Networks (WANs)
 - ✘ Radio and Satellite Networks

Local Area Networks (LANs)



- ✘ By far, most commonly used class of networks.
 - ✘ Maximum distance between nodes is limited to few kilometers.
 - ✘ Usually owned by the same organization.
 - ✘ Typical data transmission ranges between 10 Mbps (coax cable) to 100 Mbps (fiber optic, category 5 unshielded twisted pair),
 - ✘ Several architectures have been standardized (802 LANs):
 - ⊕ Ethernet (CSMA/CD), Fast Ethernet
 - ⊕ Token Bus
 - ⊕ Token Ring
 - ⊕ FDDI

Metropolitan Area Networks (MANs)



- ✘ A relatively new class of networks, intermediate between LANs and WANs,
- ✘ Support moderate (Data, Voice and Video at 1 Mbps) to high data rates,
- ✘ MANs are optimized for a larger geographical area than LANs, ranging from several blocks of buildings to entire cities,
- ✘ Standards include FDDI, FDDI-II and IEEE 802.6 (DQDB).

Wide Area Networks (WANs)



- ✘ Cover a wide geographical area,
- ✘ Communication links are provided by telephone companies, or other common carriers,
- ✘ Transmission speeds are usually restricted,
- ✘ Transmission quality is inferior to LAN one,
- ✘ WAN's architecture is usually more complex than LAN's:
 - ✘ Need for efficient routing and congestion control algorithms,
- ✘ Many implementations of vendor architectures.

Radio and Satellite Networks



- ✘ Two basic subclasses of wireless networks:
 - ✘ Terrestrial radio networks,
 - ✘ Satellite networks.

Communication Networks



- ✘ Communication networks can be classified as:
 - ✘ Broadcast networks, or
 - ✘ Switched networks.

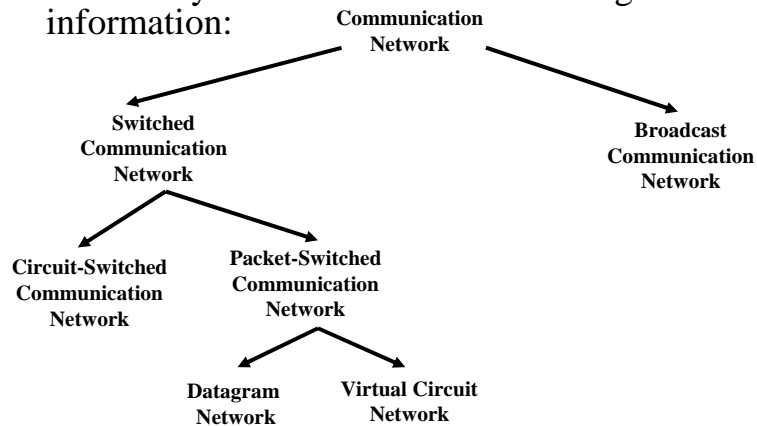
Broadcast networks



- ✘ In any broadcast network, stations communicate over a shared medium,
- ✘ No need for intermediate node,
- ✘ Need for medium access control algorithm.
- ✘ Three types of broadcast networks:
 - ✘ Packet radio networks,
 - ✘ Satellite networks, and
 - ✘ Local area networks.

A Taxonomy of Communication Networks

- ✘ Communication networks can be classified based on the way in which the nodes exchange information:



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Switched networks

- ✘ In switched networks, communication facilities are shared among users.
- ✘ Three primary switching techniques:
 - ✘ Circuit switching
 - ✘ Message switching, and
 - ✘ Packet switching.

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Switching Techniques: Circuit Switching

- ✘ Commonly used in the public telephone system.
- ✘ Exclusive dedication of a portion of the available bandwidth to carry traffic between a source and a destination.
- ✘ Allocation of the required bandwidth is achieved using:
 - ✘ Frequency Division Multiplexing (FDM)
 - ✘ Time Division Multiplexing (TDM)

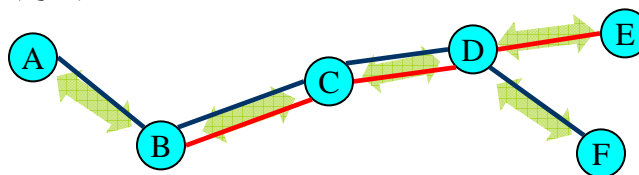
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Circuit Switched Networks

- ✘ Telephone network typically
 - ✘ All resources (e.g. communication links, buffers) needed by a “call” are reserved for its entire duration,
 - ✘ Resource reservation (i.e. resources are always available when needed by a call) guarantees „quality of service” (QoS)



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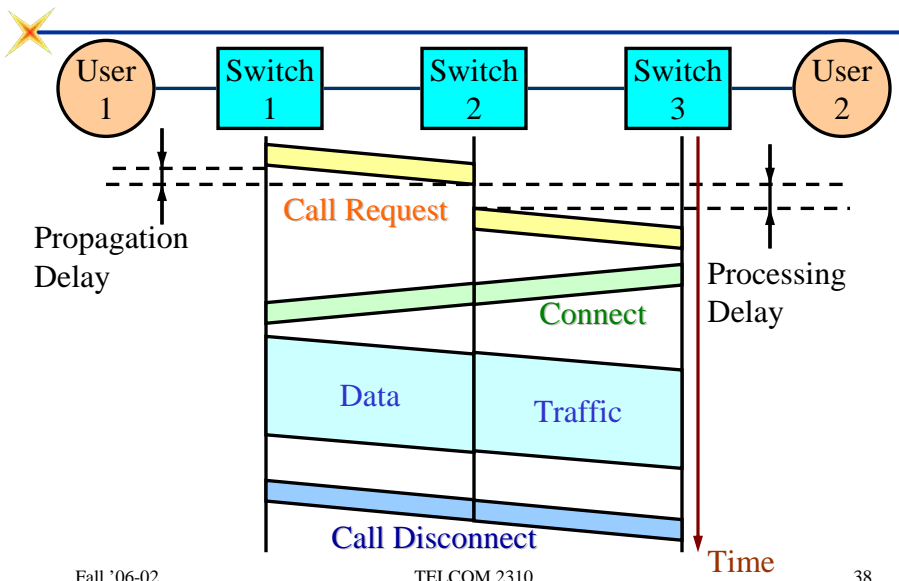
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Circuit Switching

- ✦ Call requires three phases:
 - ✦ Connection phase: a circuit is set up between source and destination,
 - ✦ Transmission phase: traffic exchange takes place,
 - ✦ Termination phase: the call is disconnected.

Circuit Switching Networks



Circuit Switching Networks



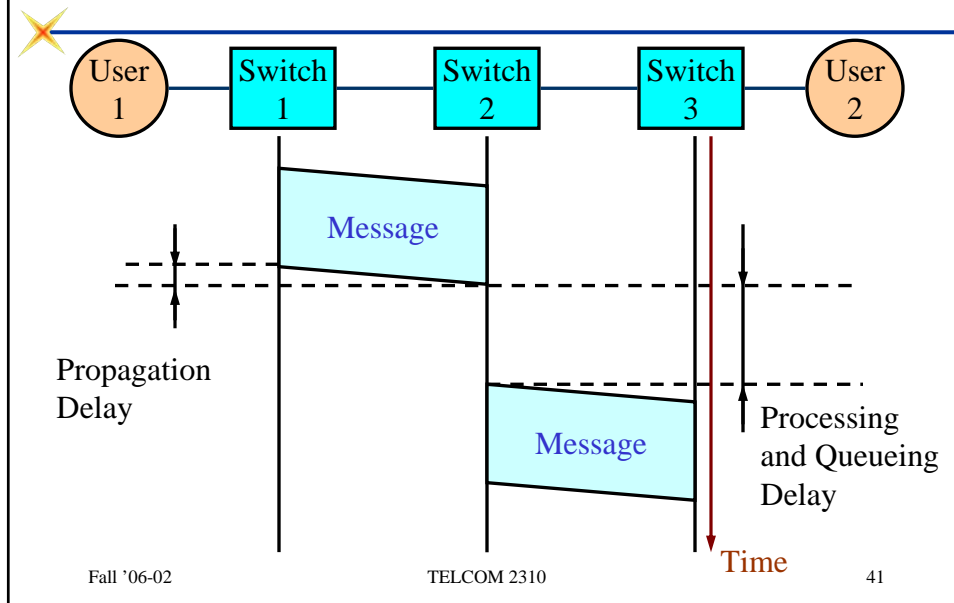
- ✘ Delays for setting up connections can be high.
 - ✘ Ordinary telephone lines:
 - ⊕ Call setup is on the order of 5 to 25 seconds after completion of dialing.

Message Switching Networks



- ✘ A physical circuit is shared among multiple users.
 - ✘ Leased communication facilities are used.
- ✘ Data enters the network in the form of “messages”
 - ✘ Messages are stored and subsequently forwarded.
 - ⊕ No circuit switching delays are involved.
 - ⊕ Queueing delays occur.
 - ⊕ Message lengths are slightly longer because of headers.

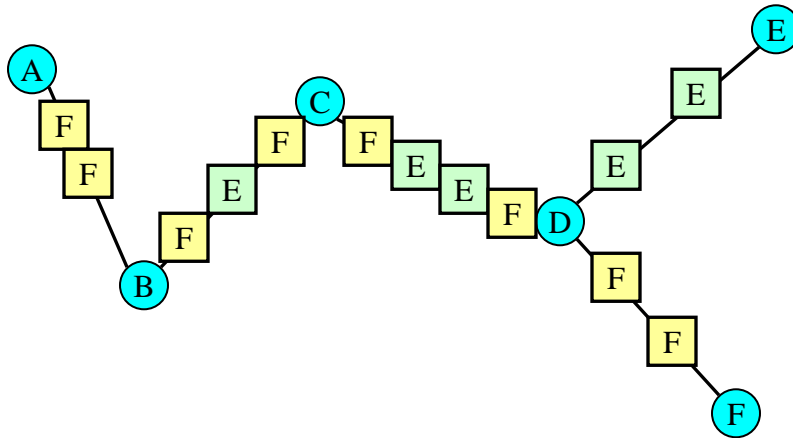
Message Switching Networks



Packet Switching Networks

- ✘ Equivalent to message switching for short messages.
 - ✘ Maximum message length for transmission is imposed.
 - ✘ Any message exceeding the maximum is broken up into shorter units called “packets”.
- ✘ Packets traversing a network share network resources with other packets – statistical sharing of resources
 - ✘ Demand for resources may exceed amount of the resources available: contention

Packet Switching Networks

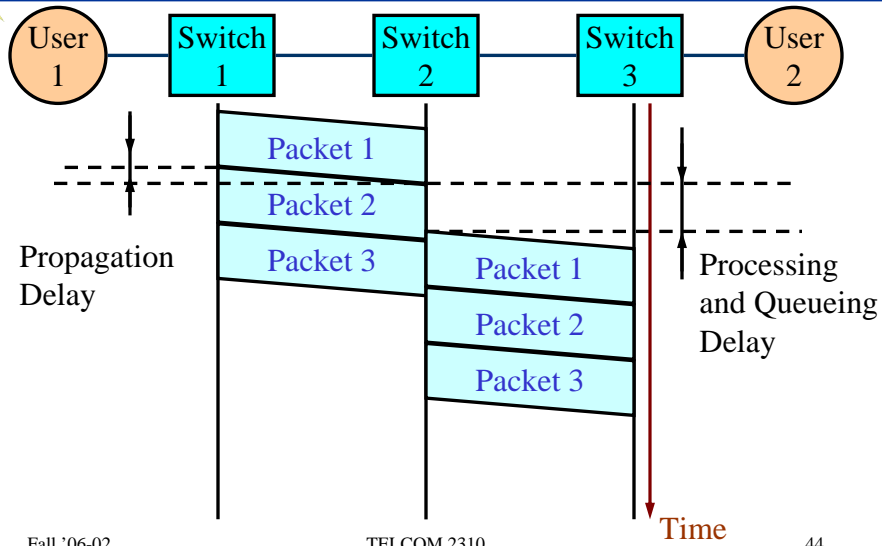


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Packet Switching Networks



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Performance Tradeoffs



✘ Three types of delay:

- ✘ Propagation delay: time for the signal to propagate from the source to the receiver (depends on the wave propagation speed, in a wire $200 \text{ mln m/s} = 200 \text{ m}/\mu\text{s}$),
- ✘ Transmission time: time needed to transmit the signal representing a block of data – depends on a link data rate,
- ✘ Processing and queueing delay: time needed to perform tasks necessary to relay a message/packet from one link to another in a given node, as well as time a message/packet has to spend waiting for the access to transmission medium – depends on the processing speed and the network load.

Performance Tradeoffs – Circuit Switching



✘ Circuit switching may lead to smaller delays if large amounts of data are exchanged.

- ✘ Elimination of the header,
- ✘ Elimination of intermediate node queueing.

Performance Tradeoffs – Packet Switching



- ✘ A major benefit: the pipelining effect.
- ✘ Simultaneous use of communication circuits allows:
 - ✘ Considerable gain in efficiency,
 - ⊕ Shorter delays, despite inclusion of headers for each packet.
 - ✘ Lower probability of retransmission,
 - ⊕ Shorter messages are less likely to have errors than longer ones,
 - ⊕ Errors do not cause retransmission of entire messages, but only of relatively shorter packets.
 - ✘ Packets can be routed independently, possibly minimizing congestion.

Performance Tradeoffs



- ✘ Packet switching provides flexibility in meeting the user needs.
 - ✘ Example: the needed rate is 75 kbps while the channel rate is 64 kbps
 - ⊕ The use of packet switching meets the demands of the user more easily.

Performance Tradeoffs



- ✘ Statistical sharing of resources can be more efficient
 - ✘ Consider a 1 Mbps communication link
 - ✘ Each user requires 100 kbps when transmitting, but sends 10% of the time,
- ✘ Circuit switching:
 - ✘ Each caller is allocated 100 kbps capacity,
 - ✘ At most 10 callers are supported.
- ✘ Packet switching:
 - ✘ With 35 ongoing calls, probability that 10 or more callers are simultaneously active is about 0.00174,
 - ✘ Can support many more callers, with small probability of contention
- ✘ If user traffic is “bursty” (on/off), then packet switching can be more efficient than circuit switching.

Performance Tradeoffs



- ✘ The relative performance of circuit switching and packet switching depends on:
 - ✘ The quality of service requirements of the application
 - ⊕ End-to-end delay bounds,
 - ⊕ Jitter control.
 - ✘ The traffic pattern,
 - ⊕ Burstiness vs constant bit rate,
 - ✘ Connection setup overhead.

Packet Switching Techniques



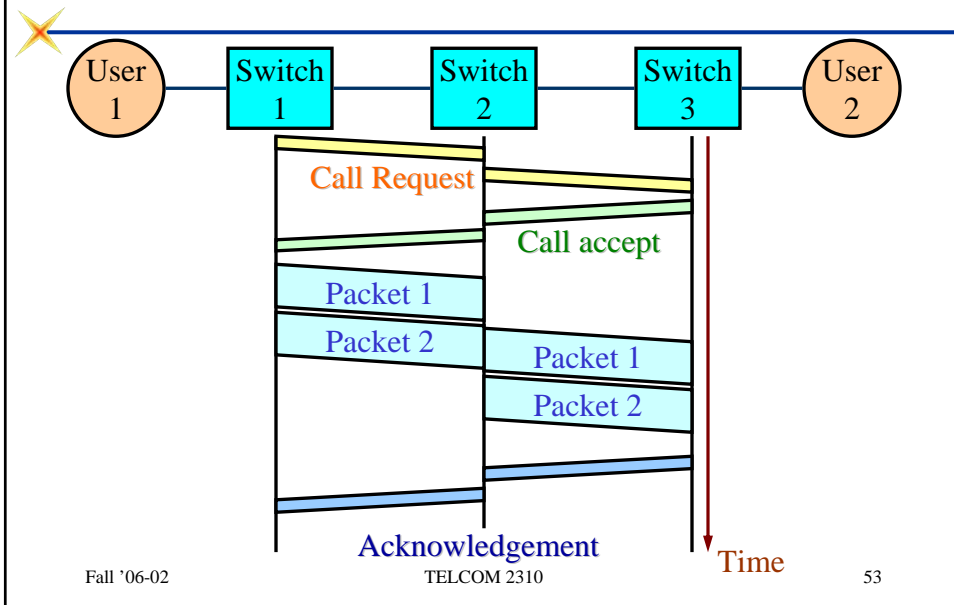
- ✘ Two basic approaches to packet switching are common:
 - ✘ Datagram packet switching,
 - ✘ Virtual circuit packet switching.

Virtual Circuit Packet Switching



- ✘ An initial phase is used to setup a fixed route.
 - ✘ Similar to circuit switching, except that a delay occurs at each node,
 - ✘ Call request and call accept must both wait their turns on transmission.

Virtual Circuit Packet Switching



Virtual Circuit Packet Switching

- ✘ Upon path setup, the virtual circuit appears to the user as a dedicated circuit.
 - ✘ In reality, the circuit is shared among multiple users.
- ✘ Destination address is no longer required.
 - ✘ Only a virtual circuit number is needed to identify the destination.
 - ✘ Packets have shorter headers and fixed routing makes possible fast packet switching.

Datagram Packet Switching



- ✘ Datagram Packet Switching does not require a call setup
- ✘ For short transactions, it may be faster
- ✘ Individual datagrams are routed independently
 - ✘ Increases processing overhead at the router
 - ⊕ Routing table lookups

Virtual Circuit Service Characteristics



- ✘ Guaranteed, reliable delivery
 - ✘ Powerful error control
 - ✘ Sequencing of packets
 - ✘ Detection and suppression of duplicates
- ✘ Congestion control minimizes queueing delays
 - ✘ Delays, however, are more variable than they are with dedicated circuits
- ✘ Enhanced security

Datagram Service Characteristics



- ✘ The network makes a “best effort” attempt to deliver the packets
 - ✘ Each packet is treated as a separate entity with no prior route determination
 - ⊕ Packets may follow different paths to destination
 - ✘ No guarantees for reliable delivery
 - ⊕ Packets may be lost, duplicated, or may arrive out of order
- ✘ The network relies on the user application to enhance the basic datagram service

Analogy



- ✘ Telephone service \Leftrightarrow virtual circuit
 - ✘ User must set up the connection, transmit and finally disconnect.
 - ✘ End users have the illusion that they communicate through a dedicated circuit.
 - ✘ Data are received in the order they have been transmitted.
- ✘ Regular postal service \Leftrightarrow datagram
 - ✘ Letters are handled independently.
 - ✘ No guaranteed delivery. Losses are the user's responsibility.
 - ✘ Letters are not necessarily delivered in the order they have been sent.

Analogy



✘ User perspective:

- ✘ “Unsophisticated” users prefer virtual circuits.
 - ⊕ The communication subnet handles most of the functions required to provide the requested service.
- ✘ “Sophisticated” users prefer datagram service.
 - ⊕ Datagram service provides more flexibility to implement particular features.

Analogy



✘ Application perspective:

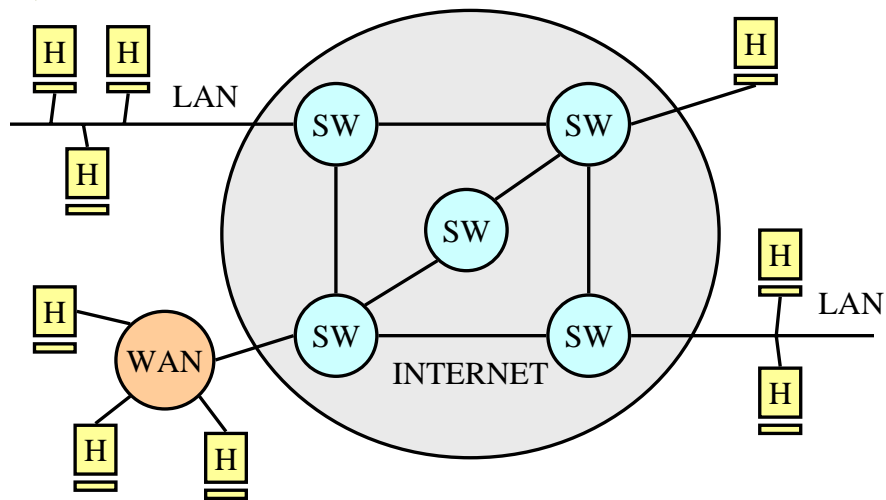
- ✘ Prior establishment of connection, although desirable, may lead to unacceptable delays for certain types of applications.
 - ⊕ Request/Reply
- ✘ Features such as error control may be detrimental to time bound applications, such as voice.
 - ⊕ Few bits in error is far more preferable than lengthy retransmission delays.
 - ⊕ For voice application a connection set up may be needed but no error control is required.

Connection Semantics



- ✘ Literature often uses the term *connection-oriented* and *connectionless* to refer to different network services.
 - ✘ Virtual circuit transmission is a special case of connection-oriented transmission
 - ✘ Datagram service is a special case of connectionless transmission

Internetworking



Internetworking



- ✘ The main goal is to provide a universal network formed out of physically different networks.
- ✘ Internetworking involves complex issues:
 - ✘ Different addressing and naming schemes
 - ✘ Different routing techniques
 - ✘ Different congestion control techniques
 - ✘ Different hardware interfaces
 - ✘ Connection oriented vs connectionless services
 - ✘ Different data unit sizes
 - ✘ Different error control techniques

The Internet



- ✘ Global scale, general purpose, heterogeneous-technologies, public, computer network
- ✘ Internet Protocol
 - ✘ Open standard: Internet Engineering Task Force (IETF) as standard body (<http://www.ietf.org>)
 - ✘ Technical basis for other types of networks
 - ⊕ Intranet: enterprise IP network
- ✘ Developed by the research community

History of the Internet

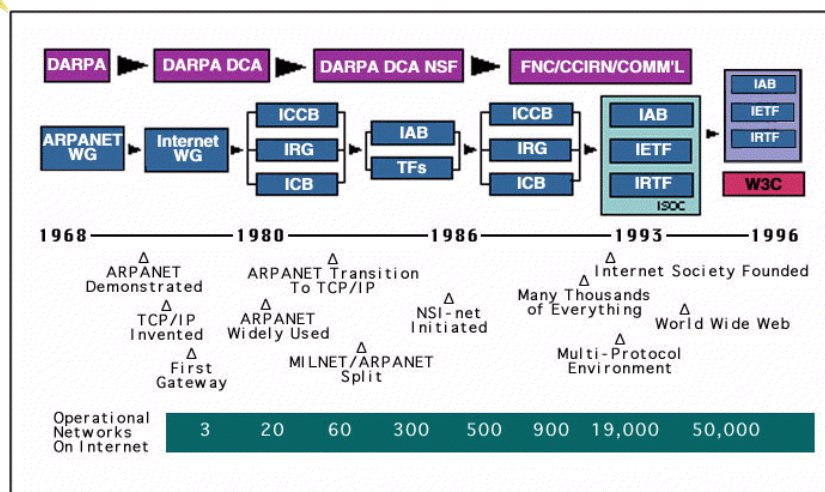
- ✘ 70's: started as a research project, 56 kbps, < 100 computers
- ✘ 80-83: ARPANET and MILNET split,
- ✘ 85-86: NSF builds NSFNET as backbone, links 6 Supercomputer centers, 1.5 Mbps, 10,000 computers
- ✘ 87-90: link regional networks, NSI (NASA), ESNet(DOE), DARTnet, TWBNet (DARPA), 100,000 computers
- ✘ 90-92: NSFNET moves to 45 Mbps, 16 mid-level networks
- ✘ 94: NSF backbone dismantled, multiple private backbones
- ✘ Today: backbones run at >10 Gbps, >300 millions computers in 150 countries

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Time Line of the Internet



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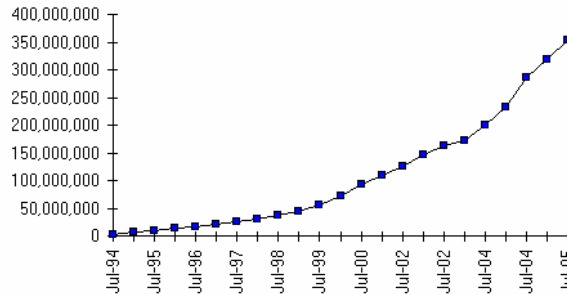
Growth of the Internet



✦ Number of Hosts on the Internet:

Aug. 1981	213
Oct. 1984	1,024
Dec. 1987	28,174
Oct. 1990	313,000
Oct. 1993	2,056,000
Apr. 1995	5,706,000
Jan. 1997	16,146,000
Jan. 1999	56,218,000
Jan. 2001	109,374,000
Jan. 2003	171,638,297
Jul 2004	285,139,107
Jul 2005	353,284,187

Internet Domain Survey Host Count



Source: Internet Software Consortium (www.isc.org)

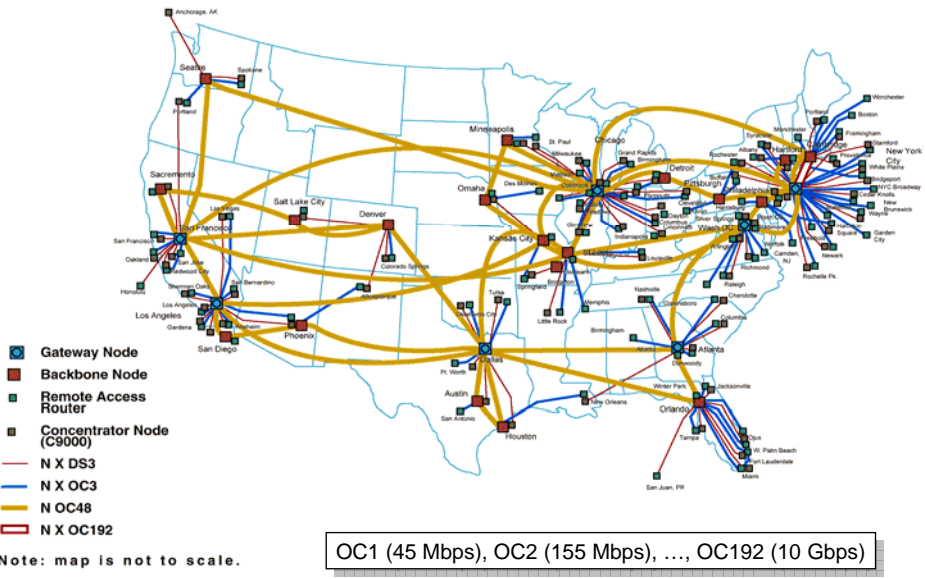
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AT&T IP BACKBONE NETWORK 2Q2000



Services Provided by the Internet



- ✘ Shared access to computing resources
 - ✘ Telnet (1970's)
- ✘ Shared access to data/files
 - ✘ FTP, NFS, AFS (1980's)
- ✘ Communication medium over which people interact
 - ✘ Email (1980's), on-line chat rooms (1990's)
 - ✘ Instant messaging, IP Telephony (2000's)
- ✘ A medium for information dissemination
 - ✘ USENET (1980's)
 - ✘ WWW (1990's)
 - Replacing newspaper, magazine
 - ✘ Audio, video (2000's): peer-to-peer systems
 - Replacing radio, telephony, TV, ...

Summary



- ✘ Introduced the basic concepts of communication networks
- ✘ Discussed switching techniques
- ✘ Presented different classes of communication networks
- ✘ Introduced the concept of Internetworking