Introduction

Course Resources
- The textbook
- The course web site
  [www.engineering.uiowa.edu/~ece_054](http://www.engineering.uiowa.edu/~ece_054) (announcements, policies, notes, assignments, solutions)
- The text companion site

Course Goals
- Introduce key principles underlying modern communication networks and applications.
- Show how these principles are applied in network design and analysis.
- Study current and emerging network protocols, architectures, technologies and applications.

NOTE: This is not a network programming or administration course! Principles, not details (which are changing fast), will be emphasized.

Main Topics:
- Network Applications: HTTP, FTP, DNS, etc.
- Network Protocols: TCP/IP, ATM, etc.
- Network Architectures (LAN, MAN, WAN).
- Multiple Access Technologies: 802.X, etc.
- Data transmission fundamentals: rate, delay.
Expected Background

- Ability to program in C will be needed to complete simple sockets programming exercises.
- Knowledge of basic probability (22S:039 level) will aid understanding of network performance issues.

Example: What is the average time $E[\tau]$ required for a successful packet transmission given that:

- Transmissions (Tx) fail independently with probability $p$.
- Success takes $T$ sec. and failure is detected after $TO > 2T$ sec.

$$E[\tau] = TP[1^{st}Tx succeeds] + (TO-E[\tau])P[1^{st}Tx fails]$$
$$= T(1-p) + (TO-E[\tau])p$$
$$= (p/(1-p))TO + T.$$

Grading

- In-class midterm exam — 25%
- Final exam — 30%
- Homework — 25%
- Labs — 15%
- Project — 10%

NOTES:
- All exams will be closed-book. One 8.5"x11" sheet of notes will be allowed for the midterm, two, for the final.
- Start your reading and assignments early. To avoid drowning in details first identify the key concepts and then relate the details to these concepts.
- All submitted work must be your own.

Historical Perspective

- Computer networks have only existed for about 40 years.
- Originally, there was a clear distinction between data transmission and other forms of communication.
- In recent years, this distinction has blurred.
- A key factor has been the widespread adoption of digital storage and transmission techniques for all forms of information.

Digital vs. Analog Transmission

- An Analog signal is continuous in time and can take on arbitrary values within some range.

Digital transmissions represent all information (data, voice, video, etc.) as a finite-rate, binary stream, e.g.,

- 20Mbps => 20 bits/μsecond

- 20 Mbps

This makes digital transmission, transmission using a finite set of analog signals, possible, e.g.,

- ASK
- PSK
Advantages of Digital Transmission

- Information sources can share a common signal set and transmission infrastructure.
- Information compression is possible (e.g. ZIP, GIF, MPEG, MP3, etc).
- Noise and bandwidth are more easily controlled through the use of ... coding for error control.
- Highly efficient modulation schemes.

The Current Telecommunications Environment

- Much of the current communications infrastructure has changed little in the past 25 years and continues to resist change.
  - We still have largely separate infrastructures for telephone, cable TV, broadcast TV, radio, and computer networks.
  - The "last mile" of local telephone infrastructure is still largely analog.
  - Many of the original network architectures developed in the '60s and '70s are still in widespread use today.

Big Changes on the Horizon

- In the last decade there has been enormous growth in the demand for Internet access.
  - As of July 2007, the Internet connected approx. 571 million host computers.
  - Its size is currently doubling every 33 months!
- The volume of data traffic now exceeds that of voice and analog video.
- The phone carriers are racing to upgrade their networks to integrate multiple services.

Internet Growth Since 1994

Source: Internet Systems Consortium (www.isc.org)
An Interesting Historical Perspective

During the first three decades of computer networking:
- Telecom infrastructure was designed to carry analog voice and video traffic.
- Central issue was efficient use of this infrastructure to support digital data communications.

In the coming decade
- Telecom infrastructure will primarily carry digital data from various sources.
- The central issue will be using this infrastructure to integrate delivery of data, voice, video, and other forms of information.

Chapter 1: Introduction

(Reading Assignment: Kurose-Ross Chapter 1)

Our goal:
- get context, overview, "feel" of networking
- more depth, detail later in course
- approach:
  - descriptive
  - use Internet as example

Overview:
- what's the Internet
- what's a protocol?
- network edge
- network core
- access net, physical media
- Internet/ISP structure
- performance: loss, delay
- security
- protocol layers, service models
- history (read on your own)

What's the Internet: "nuts and bolts" view

- millions of connected computing devices: hosts, end-systems
  - PCs workstations, servers
  - PDAs phones, toasters
  - running network apps
- communication links
  - fiber, copper, radio, satellite
  - transmission rate = bandwidth
- routers: forward packets (chunks of data)
“Cool” internet appliances

Introduction

What’s a protocol?

- protocols define format and order of communication, and actions taken after messages sent and received.
- human and network protocol examples:

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<thead>
<tr>
<th>Hi</th>
<th>Got the time?</th>
<th>2:00</th>
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What’s the Internet: "nuts and bolts" view

- protocols control sending, receiving of msgs
  - e.g., TCP, IP, HTTP, FTP, PPP
- Internet: "network of networks"
  - loosely hierarchical
  - public Internet versus private intranet
- Internet standards
  - IETF: Internet Engineering Task Force
    - RFC: Request for comments

Network edge: connection-oriented service

**Goal:** data transfer between end systems

- **handshaking:** setup (prepare for) data transfer ahead of time
  - Hello, hello back human protocol
  - set up “state” in two communicating hosts
- **TCP - Transmission Control Protocol**
  - Internet’s connection-oriented service

**TCP service [RFC 793]**

- reliable, in-order byte-stream data transfer
  - loss: acknowledgements and retransmissions
  - **flow control:**
    - helps ensure sender won’t overwhelm receiver
  - **congestion control:**
    - sends “slow down send rate” when network congestion detected.
Network edge: connectionless service

Goal: data transfer between end systems
- same as before!
- UDP - User Datagram Protocol [RFC 768]: Internet's connectionless service
  - unreliable data transfer
  - no flow control
  - no congestion control

App's using TCP:
- HTTP (Web), FTP (file transfer), Telnet (remote login), SMTP (email)

App's using UDP:
- streaming media, teleconferencing, DNS, Internet telephony

Circuit Switching: FDMA and TDMA

network resources (e.g., bandwidth) divided into "subchannels"
- subchannels allocated to calls
- subchannel is idle if not used by owning call (no sharing)
- link bandwidth divided into subchannels by
  - frequency division
  - time division

Network Core: Packet Switching

Each end-end data stream divided into packets
- user A, B packets share network resources
- each packet uses full link bandwidth
- resources used as needed

Resource contention:
- aggregate resource demand can exceed amount available
- congestion: packets queue, wait for link use
- store and forward: packets move one hop at a time
  - transmit over link
  - wait turn at next link

Packet Switching: Statistical Multiplexing

Bandwidth "division into pieces" Dedicated allocation Resource reservation

Sequence of A & B packets does not have fixed pattern ⇒ statistical multiplexing. In TDM each host gets same slot in revolving TDM frame.
Packet switching versus circuit switching

Packet switching allows more users to use network!

- 1 Mbit link
- each user:
  - 100 kbps when "active"
  - active 10% of time
- circuit-switching:
  - 10 users
- packet switching:
  - with 35 users, probability > 10 active less than .0004

\[ P[\text{>10 active}] = 1 - \sum_{k=0}^{10} \binom{35}{k} (1.1)^k (1.1)^{35-k} \]

Packet Switching: Message Segmenting

Now break the message into 5000 packets

- Each packet 1,500 bits
- 1 msec to transmit packet on one link
- pipelining: all links work in parallel
- Delay reduced from 15 sec to 5.002 sec

Packet-switching: store-and-forward

- Takes \( L/R \) seconds to transmit (push out) packet of \( L \) bits on to link at \( R \) bps
- Entire packet must arrive at router before it can be transmitted on next link: store and forward
- \[ \text{delay} = 3L/R \]

Example:

- \( L = 7.5 \) Mbits
- \( R = 1.5 \) Mbps
- \[ \text{delay} = 15 \text{ sec} \]

Assuming negligible propagation delay
Packet-switched networks: forwarding

- **Goal**: move packets through routers from source to destination
  - we'll study several path selection (i.e. routing) algorithms (chapter 4)
- **Datagram network**:
  - destination address in packet determines next hop
  - routes may change during session
  - analogy: driving, asking directions
- **Virtual circuit network**:
  - each packet carries tag (virtual circuit ID), tag determines next hop
  - fixed path (virtual circuit) determined at call setup time, remains fixed thru call
  - routers maintain per-call state

Access networks and physical media

- **Q**: How to connect end systems to edge router?
- **Residential access nets**
- **Institutional access networks** (school, company)
- **Mobile access networks**

Keep in mind:
- bandwidth (bits per second) of access network?
- shared or dedicated?

Network Taxonomy

- **Telecommunication networks**
  - Circuit-switched networks
  - Packet-switched networks
  - FDM
  - TDM
  - Networks with VCs
  - Datagram Networks

- Datagram network is **not** either connection-oriented or connectionless.
- Internet provides both connection-oriented (TCP) and connectionless services (UDP) to apps.

Residential access: point to point access

- **Dialup via modem**
  - up to 34Kbps upstream and 56Kbps downstream access to router (often less)
  - Can't surf and phone at same time: can't be "always on"
- **DSL** (digital subscriber line)
  - up to 1 Mbps upstream (today typically < 256 kbps)
  - up to 8 Mbps downstream (today typically < 1 Mbps)
  - FDM: 50 kHz - 1 MHz for downstream
    - 4 kHz - 50 kHz for upstream
    - 0 kHz - 4 kHz for ordinary telephone
Residential access: cable modems

- HFC: hybrid fiber coax
  - asymmetric: up to 2 Mbps upstream, 30 Mbps downstream
- network of cable and fiber attaches homes to ISP router
  - shared access to router among home
  - issues: congestion, dimensioning
- deployment: available via cable companies

Cable Network Architecture: Overview

Typically 500 to 5,000 homes

Institutional access: local area networks

- company/univ local area network (LAN) connects end system to edge router
- Ethernet:
  - shared or dedicated link connects end system and router
  - 10 Mbs, 100Mbps, Gigabit Ethernet
- deployment: institutions, home LANs happening now
- LANs: chapter 5
Wireless access networks

- shared wireless access network connects end system to router via base station aka "access point"
- wireless LANs:
  - 802.11b (WiFi): 11 Mbps
  - 802.11a: 54 Mbps
  - 802.11n: 500 Mbps (in development)
- wider-area wireless access
  - provided by telco operator
  - 3G ~ 384 kbps
  - WAP/GPRS in Europe
  - Emerging: WiMax (multi-Mbps over wide area)

Home networks

Typical home network components:

- DSL or cable modem
- router/firewall/NAT
- Ethernet
- wireless access point

Physical Media

- Bit: propagates between transmitter/rcvr pairs
- physical link: what lies between transmitter & receiver
- guided media:
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio

Twisted Pair (TP)

- two insulated copper wires
  - Category 3 TP: traditional phone wires, 10 Mbps Ethernet
  - Category 5 TP: similar, but with more twists, 100Mbps Ethernet

Coaxial cable:

- wire (signal carrier) within a wire (shield)
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
- broadband:
  - multiple channels on cable
  - HFC

Fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 5 Gbps)
- low error rate: repeaters spaced far apart; immune to electromagnetic noise
**Physical media: radio**

- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation

  - environment effects:
    - reflection
    - obstruction by objects
    - interference

**Radio link types:**

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., WiFi)
  - 1 Mbps, 54 Mbps, 248 Mbps
- wide-area (e.g., cellular)
  - e.g. 36-1000s of kbps
- satellite
  - up to 45 Mbps channel (or multiple smaller channels)
  - 270 ms end-end delay
  - geosynchronous versus LEOs (delay vs. cost)

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**Internet structure: network of networks**

- roughly hierarchical
- at center: " Tier-1" ISPs (e.g., UUNet, BBN/Genuity, Sprint, AT&T), national/international coverage
  - treat each other as equals

Tier-1 providers also interconnect at public network access points (NAPs)

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**Tier-1 ISP: e.g., Sprint**

Sprint US backbone network

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**Internet structure: network of networks**

- " Tier-2" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs

Tier-2 ISPs also peer privately with each other, interconnect at NAP
**Internet structure: network of networks**

- "Tier-3" ISPs and local ISPs
  - last hop ("access") network (closest to end systems)

- Tier-1 ISP
  - Tier-2 ISP
  - NAP
  - Tier-2 ISP
  - Tier-1 ISP
- Tier-2 ISP
  - Tier-3 ISP
  - local ISP
  - local ISP

Local and tier-3 ISPs are customers of higher tier ISPs connecting them to rest of Internet

**Delay & loss in packet-switched networks**

- packets may encounter delay and even loss on end-to-end path.
- **Four sources of delay at each hop:**
  1. nodal processing delay:
     - bit error-check
     - output link selection (routing)
  2. queueing delay
     - wait at output link for transmission (depends on router congestion level)
     - buffer overflow \( \Rightarrow \) loss
  3. Transmission delay:
     - \( R \) = link transmission rate (bps)
     - \( L \) = packet length (bits)
     - time to send bits into link = \( L/R \)
  4. Propagation delay:
     - \( d \) = length of physical link
     - \( s \) = propagation speed in medium (~2x10^8 m/sec)
     - propagation delay = \( d/s \)

**Internet structure: network of networks**

- a packet passes through many networks!

**Delay in packet-switched networks**

3. Transmission delay:
   - \( R \) = link transmission rate (bps)
   - \( L \) = packet length (bits)
   - time to send bits into link = \( L/R \)

4. Propagation delay:
   - \( d \) = length of physical link
   - \( s \) = propagation speed in medium (~2x10^8 m/sec)
   - propagation delay = \( d/s \)

**Note:** \( s \) and \( R \) are very different quantities!
**Caravan analogy**

- Cars "propagate" at 100 km/hr
- Toll booth takes 12 sec to service a car (transmission time)
- Caravan takes 100 km/(100 km/hr) = 1 hr
- Q: How long until caravan is lined up before 2nd toll booth?
- A: 62 minutes

**Caravan analogy (more)**

- Cars now "propagate" at 1000 km/hr
- Toll booth now takes 1 min to service a car
- Q: Will cars arrive to 2nd booth before all cars served at 1st booth?
- Yes! After 7 min, 1st car at 2nd booth and 3 cars still at 1st booth.
- 1st bit of packet can arrive at 2nd router before packet is fully transmitted at 1st router!
- See Ethernet applet at AWL Web site

**Nodal delay**

\[ d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}} \]

- \( d_{\text{proc}} \) = processing delay
  - Typically a few microseconds or less
- \( d_{\text{queue}} \) = queuing delay
  - Depends on congestion
- \( d_{\text{trans}} \) = transmission delay
  - \( \approx L/R \), significant for low-speed links
- \( d_{\text{prop}} \) = propagation delay
  - A few microseconds to hundreds of msecs

**Queueing delay (revisited)**

- \( R \) = link transmission rate (bps)
- \( L \) = packet length (bits)
- \( a \) = average packet arrival rate
- Traffic intensity = \( La/R \)
  - \( La/R \approx 0 \): average queueing delay small
  - \( La/R \rightarrow 1 \): delays become large
  - \( La/R > 1 \): more "work" arriving than can be serviced \( \Rightarrow \) average delay infinite!
“Real” Internet delays and routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

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Throughput

- **throughput**: rate (bits/time unit) at which bits transferred between sender/receiver
  - **instantaneous**: rate at given point in time
  - **average**: rate over long(er) period of time

Throughput (more)

- **$R_s < R_c$**: What is average end-end throughput?

Packet loss

- **queue** (aka buffer) preceding link in buffer has finite capacity
- when packet arrives to full queue, packet is dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not retransmitted at all
- Packets may also be dropped if they are not successfully delivered within a given time constraint.

Packet loss (more)

- **$R_s > R_c$**: What is average end-end throughput?
Throughput: Internet scenario

- per-connection end-end throughput: \( \min(R_c, R_s, R/10) \)
- in practice: \( R_c \) or \( R_s \) is often bottleneck

Protocol “Layers”

Networks are complex!
- many “pieces”:
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware, software

Question:
Is there any hope of organizing structure of network?
Or at least our discussion of networks?

Why layering?

Dealing with complex systems:
- explicit structure allows identification, relationship of complex system’s pieces
- layered reference model for discussion
- modularization eases maintenance, updating of system
  - change of implementation of layer’s service transparent to rest of system
  - e.g., change in gate procedure doesn’t affect rest of system
- layering considered harmful?

Internet protocol stack

- application: supporting network applications
  - FTP, SMTP, STTP
- transport: host-host data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - PPP, Ethernet
- physical: bits “on the wire”
**ISO/OSI reference model**

- **Presentation**: Allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- **Session**: Synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these layers!
  - These services, if needed, must be implemented in application
  - Needed?

**Protocol layering and data**

Each layer takes data from above
- Adds header information to create new data unit
- Passes new data unit to layer below

**Encapsulation**

- Source
- Destination
- Message
- Segment
- Datagram
- Frame

**Introduction: Summary**

Covered a "ton" of material!
- Internet overview
- What's a protocol?
- Network edge, core, access network
  - Packet-switching versus circuit-switching
- Internet/ISP structure
- Performance: loss, delay
- Layering and service models

You now have:
- Context, overview, "feel" of networking
- More depth, detail to follow!