Chapter 1: Introduction

Our goal:
- get "feel" and terminology
- 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
- protocol layers, service models
- network modeling

Chapter 1: roadmap

1.1 What is the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History

What’s the Internet: “nuts and bolts” view

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

- IP picture frame
  
  http://www.ceiva.com/

- World's smallest web server
  
  http://www-ccs.cs.umass.edu/~shri/iPic.html

- Web-enabled toaster+weather forecaster

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

- **protocols** control sending and receiving of msgs
  - e.g., TCP, IP, HTTP, FTP, PPP

- Internet:
  - "network of networks"
    - loosely hierarchical
    - public Internet vs. private intranet

- Internet standards
  - RFC:
    - Request for comments
  - IETF:
    - Internet Engineering Task Force (www.ietf.org)

What's the Internet: a service view

- communication infrastructure enables distributed applications:
  - Web,
  - email,
  - games,
  - e-commerce,
  - file sharing

- communication services provided to apps:
  - Connectionless: unreliable
  - connection-oriented: reliable

What's a protocol?

human protocols:

- "what's the time?"
- "I have a question"
- introductions

... specific msgs sent
... specific actions taken when msgs received, or other events

network protocols:

- machines rather than humans
- all communication activity in Internet governed by protocols

protocols define:

- format,
- order of msgs sent and received among network entities, and
- actions taken on msg transmission, receipt
**What's a protocol?**

A human protocol and a computer network protocol:

- **Human Protocol:**
  - Q: Other human protocols?
  - Hi
  - Hi
  - Got the time?
  - 2:00

- **Computer Network Protocol:**
  - TCP connection request
  - TCP connection response

**Chapter 1: roadmap**

1.1 What is the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History

**A closer look at network structure:**

- **Network edge:** applications and hosts
- **Network core:**
  - routers
  - network of networks
- **Access networks, physical media:** communication links

**The network edge:**

- **End systems (hosts):**
  - run application programs
  - e.g. Web, email
  - at "edge of network"
- **Client/server model**
  - client host requests, receives service from always-on server
  - e.g. Web browser/server; email client/server
- **Peer-peer model:**
  - minimal (or no) use of dedicated servers
  - e.g. Gnutella, KaZaA
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:**
  - sender won't overwhelm receiver
- **congestion control:**
  - senders "slow down sending rate" when network congested

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

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

Network edge: connectionless service

**Goal:** data transfer between end systems

- **same as before!**

- **UDP - User Datagram Protocol** [RFC 768]:
  - connectionless
  - unreliable data transfer
  - no flow control
  - no congestion control

Chapter 1: roadmap

1.1 What *is* the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History

The Network Core

- mesh of interconnected routers
- *the* fundamental question: how is data transferred through net?
- circuit switching: dedicated circuit per call: telephone net
- packet-switching: data sent thru net in discrete "chunks"
**Network Core: Circuit Switching**

End-end resources reserved for "call"
- link bandwidth, switch capacity
- dedicated resources: no sharing
- circuit-like (guaranteed) performance
- call setup required

**Network Core: Circuit Switching**

network resources (e.g., bandwidth) divided into "pieces"
- pieces allocated to calls
- resource piece idle if not used by owning call (no sharing)

**Circuit Switching: FDM and TDM**

Example:
- 4 users

<table>
<thead>
<tr>
<th>FDM</th>
<th>TDM</th>
</tr>
</thead>
<tbody>
<tr>
<td>frequency</td>
<td>frequency</td>
</tr>
<tr>
<td>time</td>
<td>time</td>
</tr>
</tbody>
</table>

- FDM: 4 users
- TDM: 4 users

**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

Bandwidth division into “pieces”
- Dedicated allocation
- Resource reservation

- Transmit over a link & wait turn at next link
- Node receives complete packet before forwarding
Packet Switching: Statistical Multiplexing

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

1 Mb/s link
- each user:
  - 100 kb/s when "active"
  - active 10% of time

10 users
- circuit-switching:
  - max. of 10 users
- packet switching:
  - with 35 users, probability ( > 10 active ) < 0.0004

Packet switching allows more users to use network!

Packet-switching: store-and-forward

Takes L/R seconds to transmit (push out) packet of L bits on to link of R bps

Example:
- L = 7.5 Mbits
- R = 1.5 Mbps
- delay = 15 sec. end to end

Q: How to provide circuit-like behavior?
- bandwidth guarantees needed for audio/video apps
  - still an unsolved problem (chapter 6)
Packet Switching: Message Segmenting

Now break up the message into 5000 packets
- Each packet 1,500 bits
- 1 msec to transmit packet on one link
- **pipelining**: each link works in parallel
- Delay reduced from 15 sec to 5.002 sec

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** (ala Internet): 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 determined at **call setup time**, remains fixed thru call
  - routers maintain per-call state

Network Taxonomy

- **Telecommunication networks**
- **Circuit-switched networks**
  - FDM
  - TDM
- **Packet-switched networks**
  - 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.

Chapter 1: roadmap

1.1 What is the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History
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?

Residential access: point to point access

- Dialup via modem
  - up to 56Kbps direct access to router (often less)
  - Can’t surf and phone at same time: can’t be “always on”

- ADSL: asymmetric 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 30Mbps downstream, 2 Mbps upstream
- network of cable and fiber attaches homes to ISP router
  - homes share access to router
- deployment: available via cable TV companies

Diagram: http://www.cabledatamenews.com/cmic/diagram.html
Company 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, 1000 Mbps (Gigabit) Ethernet
- 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,g: up to 54 Mbps
- wider-area wireless access
  - provided by telco operator
  - 3G ~ 384 kbps
  - Will it happen??
  - WAP/GPRS in Europe

Home networks

Typical home network components:
- ADSL 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: traditional phone wires, 10 Mbps Ethernet
- Category 5: 100Mbps Ethernet
Physical Media: coax, fiber

Coaxial cable:
- two concentric copper conductors
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
- broadband:
  - multiple channel 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

Radio link types:
- terrestrial microwave
  - e.g., up to 45 Mbps channels
- LAN (e.g., WIFI)
  - 2 Mbps, 11 Mbps
- wide-area (e.g., cellular)
  - e.g., 3G: hundreds of kbps
- satellite
  - up to 50 Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude

Chapter 1: roadmap

1.1 What is the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History

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 ISP: e.g., Sprint

Sprint US backbone network

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

- a packet passes through many networks!

Local and tier-3 ISPs are customers of higher tier ISPs connecting them to rest of Internet
Chapter 1: roadmap

1.1 What is the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History

How do loss and delay occur?

packets queue in router buffers
  - enqueue and dequeue
  - packet arrival rate to link may exceed output link capacity
  - packets queue, wait for turn

four sources of packet delay

1. nodal processing:
   - check bit errors
   - determine output link
2. queueing
   - time waiting at output link for transmission
   - depends on congestion level of router

Delay in packet-switched networks

3. Transmission delay:
   - $R =$ link bandwidth (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 (~$2 \times 10^8$ 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)
- car~bit; caravan ~ packet
- Q: How long until caravan is lined up before 2nd toll booth?

  - Time to "push" entire caravan through toll booth onto highway = 12*10 = 120 sec
  - Time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr)= 1 hr
  - 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 serviced 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 microsecs or less
- \( d_{\text{queue}} \) = queuing delay
  - Depends on congestion
- \( d_{\text{trans}} \) = transmission delay
  - \( = L/R \), significant for low-speed links
- \( d_{\text{prop}} \) = propagation delay
  - A few microsecs to hundreds of msecs

**Queueing delay (revisited)**

- \( R \)=link bandwidth (bps)
- \( L \)=packet length (bits)
- \( a \)=average packet arrival rate

\[ \text{traffic intensity} = La/R \]

- \( La/R \sim 0 \): average queueing delay small
- \( La/R \rightarrow 1 \): delays become large
- \( La/R > 1 \): more "work" arriving than can be serviced, average delay infinite!
"Real" Internet delays and routes

- What do "real" Internet delay & loss look like?
- **Traceroute program**: provides delay measurement from source to router along end-end Internet path towards destination. For all *i*:
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.

---

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

---

Chapter 1: roadmap

1.1 What is the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History
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?

Organization of air travel

<table>
<thead>
<tr>
<th>ticket (purchase)</th>
<th>ticket (complain)</th>
</tr>
</thead>
<tbody>
<tr>
<td>baggage (check)</td>
<td>baggage (claim)</td>
</tr>
<tr>
<td>gates (load)</td>
<td>gates (unload)</td>
</tr>
<tr>
<td>runway takeoff</td>
<td>runway landing</td>
</tr>
<tr>
<td>airplane routing</td>
<td>airplane routing</td>
</tr>
</tbody>
</table>

- a series of steps

Layering of airline functionality

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”

**Layering: logical communication**

Each layer:
- distributed
- “entities” implement layer functions at each node
- entities perform actions, exchange messages with peers

**E.g.: transport**

- take data from app
- add addressing, reliability check info to form “datagram”
- send datagram to peer
- wait for peer to ack receipt
- analogy: post office
Layering: physical communication

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

Chapter 1: roadmap

1.1 What is the Internet?
1.2 Network edge
1.3 Network core
1.4 Network access and physical media
1.5 Internet structure and ISPs
1.6 Delay & loss in packet-switched networks
1.7 Protocol layers, service models
1.8 History

Internet History

1961-1972: Early packet-switching principles

- 1961: Kleinrock -
  - queueing theory shows effectiveness of packet-switching
- 1964: Baran -
  - packet-switching in military nets
- 1967: ARPAnet
  - conceived by Advanced Research Projects Agency
- 1969: first ARPAnet node operational
- 1972:
  - ARPAnet demonstrated publicly
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes
Internet History

1972-1980: Internetworking, new and proprietary nets
- 1970: ALOHAnet satellite network in Hawaii
- 1974: Cerf and Kahn - architecture for interconnecting networks
- late 70's: proprietary architectures: DECnet, SNA, XNA
- late 70's: switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Cerf and Kahn's interconnection principles:
- minimalism, autonomy - no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control

define today's Internet architecture

1983: deployment of TCP/IP
1982: SMTP e-mail protocol defined
1983: DNS defined for name-to-IP-address translation
1985: FTP protocol defined
1988: TCP congestion control

Internet History

1980-1990: new protocols, a proliferation of networks
- new national networks: Csnet, BITnet, NSFnet, Minitel
- 100,000 hosts connected to confederation of networks

Internet History

1990, 2000's: commercialization, the Web, new apps
- Early 1990's: ARPAnet decommissioned
- early 1990's: Web
  - hypertext [Bush 1945, Nelson 1960's]
  - HTML, HTTP: Berners-Lee
  - 1994: Mosaic, later Netscape
- late 1990's: commercialization of the Web

Late 1990's - 2000's:
- more killer apps: instant messaging, P2P file sharing
- network security to forefront
- est. 50 million host, 100 million+ users
- backbone links running at Gbps

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
- history

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